DOE Bioenergy Technologies Office (BETO)
2019 Project Peer Review

Small Scale Decentralized Fuel Production Facilities via Advanced Heat Exchanger-Enabled Biorefineries
DOE Award EE0007964

March 5, 2019
Technology Session Area Review

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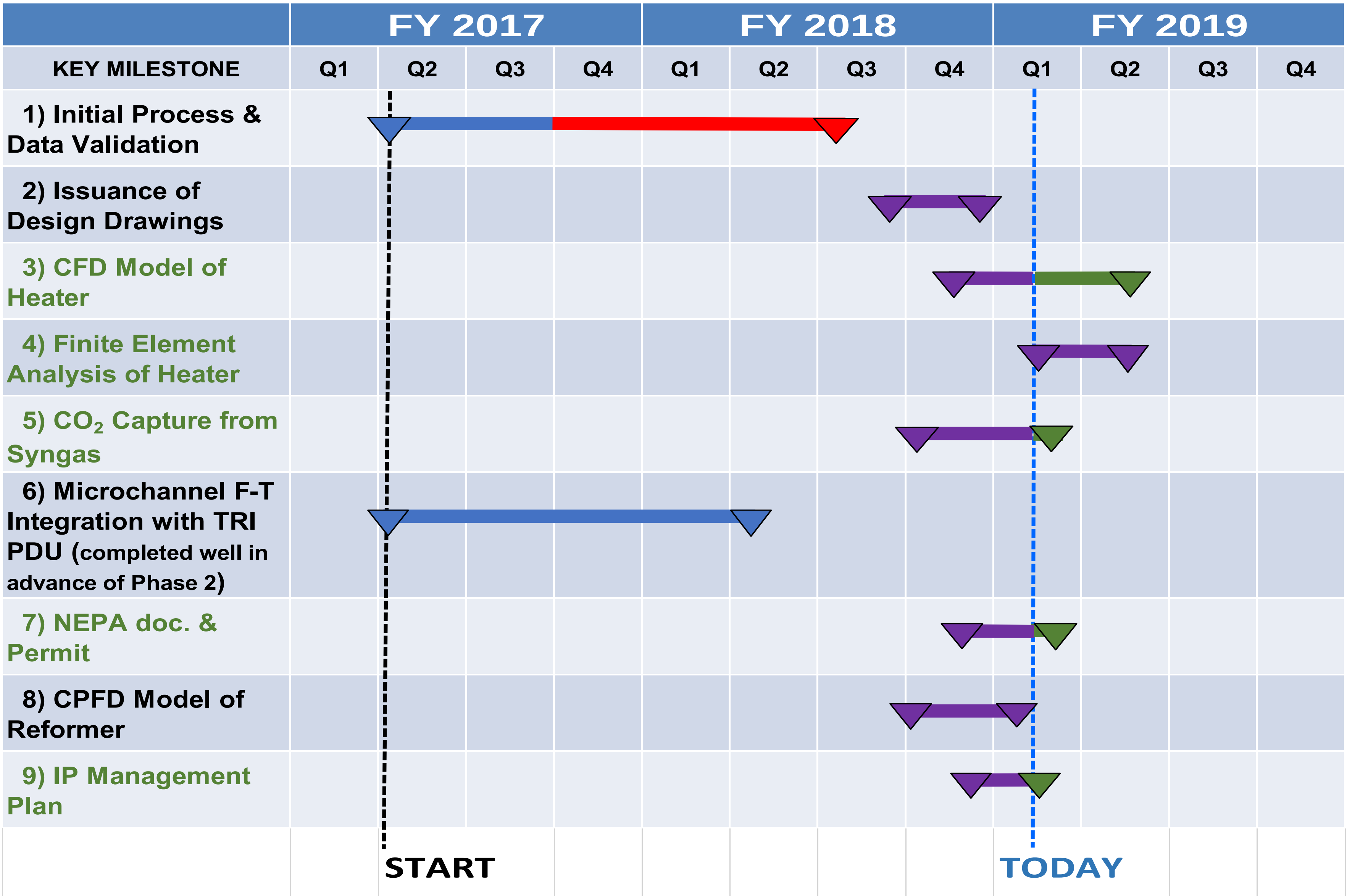
TRI

Goal Statement

- Process Intensification to **Go Small** to **Go BIG**
  Design and develop a 2nd generation biorefinery capable of decentralized, small scale biofuel production with fewer unit operations for enhanced biofuel yield per ton of cellulosic biomass at lower CapEx and OpEx to facilitate wide deployment
- Meet DOE/EERE/BETO objectives:
  - *Dramatically reduce dependence on imported oil*
  - *Spur the creation of the domestic bio-industry*
- Drop-in cellulosic biofuel cost target < $2/GGE

Key Milestones



Project Budget Table

	Original Project Cost (Estimated)			Project Spending and Balance		Final Project Costs
Budget Periods / Tasks	**DOE Funding**	**Project Team Cost Shared Funding**		**Spending to Date**	**Remaining Balance**	**What funding is needed to complete the task / project**
BP1						
1 - Process and Data Validation	119,252	119,252		293,805	--	Done
BP2						
2 – Mechanical Design of Advanced Heater	94,316	84,881		65,136	114,061	
3 – Combustion Modeling	126,000	112,000		50,000	188,000	
4 – Finite Element Analysis	120,000	90,000		--	210,000	
5 – Carbon Dioxide Capture	150,000	85,000		55,469	179,531	
6 – Microchannel FT	10,000	10,000		--	20,000	
7 – NEPA Documentation	25,000	25,000		800	49,200	
8 – CPFD Modeling	145,000	95,000		130,000	110,000	
9 – IP Management Plan	25,000	25,000		1,200	48,800	
TOTALS (as of 12.31.18)				596,411	919,592	

Quad Chart Overview

Timeline

- Project start date – 01/15/2017
- Original project end date 1/31/2019
  Revised project end date 07/31/19
  (longer validation period)
- 75% complete

Budget

	Pre FY 17	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date
DOE Funded			72,478	685,523
Project Cost Share (Comp.)*		109,700	207,721	440,581

Barriers

- Barriers addressed
  - ADO-A. Process Integration
  - ADO-D. Technology Uncertainty of Integration & Scaling
  - ADO-C. Codes, Stds & Approval for Use
  - ADO-F. First-of-a-Kind Technology Development
  - At-E. Quantification of Economic, Environmental & Other Benefits & Costs

Partners

- Velocys, RTI
  - Level of involvement, FY 17-18. [Velocys (5%); RTI (20%)]
- Other interactions/collaborations
  - CPFD, LLC
  - Siemens PLM Software Inc.
  - H.C. Vidal
  - Singularis Solutions

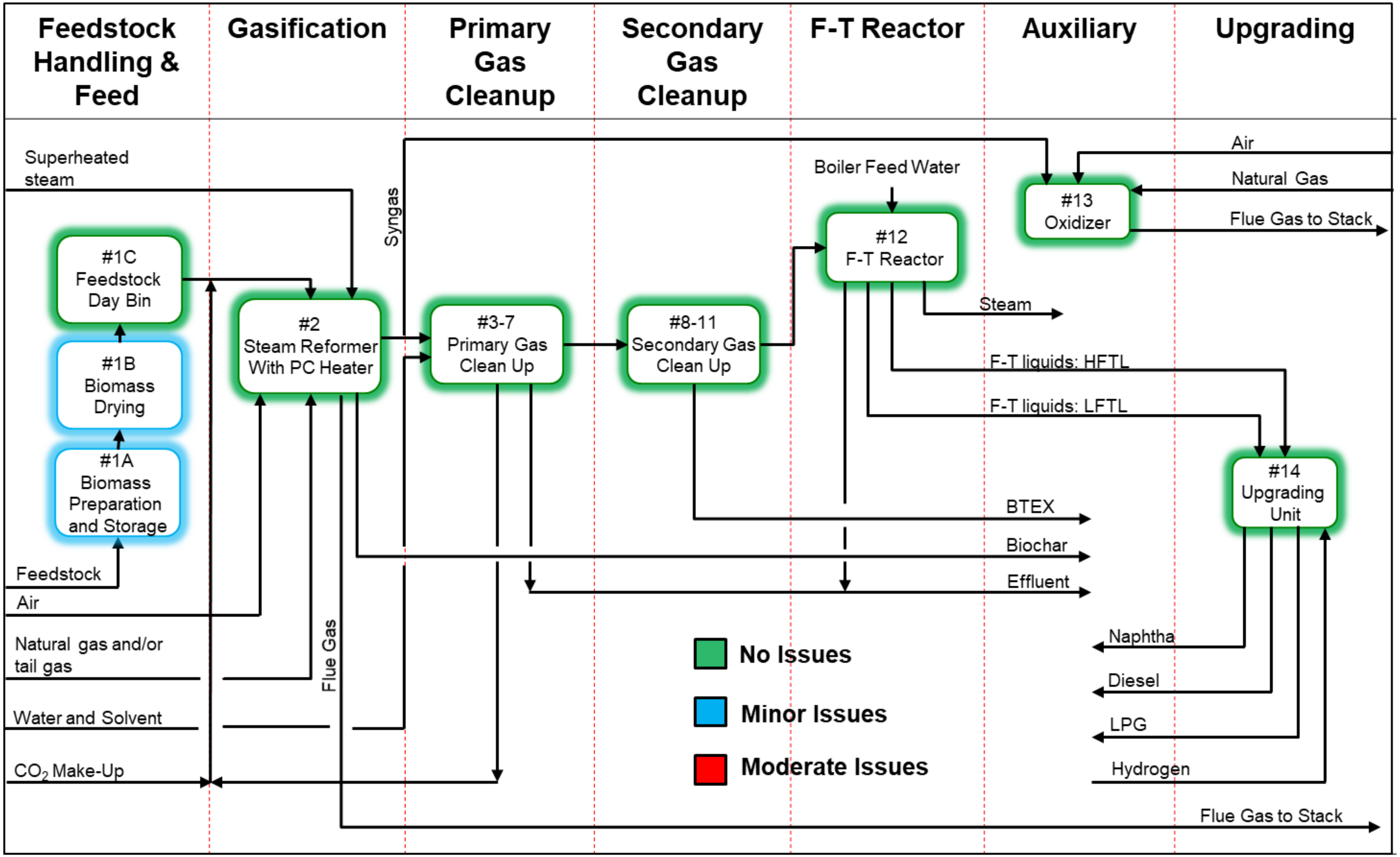
1 - Project Overview

- History, context & high-level objectives of the project
  - *FOA No. DE-FOA-0001232 Project Development for Pilot Scale manufacturing of Biofuels, Bioproducts and Biopower*
  - *Project team (TRI, RTI & Velocys) – no changes*
  - *Planned: Initial Process & Data Validation; Component Design and Simulation. Achieved: Successful Validation; Component Design and Simulation on schedule*
  - *Design & simulation delayed due to longer validation and the revised scheduled has been approved*
  - *On track to meet Phase 1 objectives*
  - *No showstoppers apparent; no directional changes required*
  - *Project schedule takes into account the availability of resources to complete the remaining project*

2 – Approach (Technical)

- *Overall technical approach: Design, test and validate the high impact process intensification improvements to "first generation" IBR*
  - *Experimental validation of individual, new unit ops*
  - *Run simulations to validate model, scaleup and confirm performance improvement*
  - *Design, fabricate, install, commission and test the integrated Process Demonstration Unit (PDU) to demonstrate improvements*
- *Critical success factors:*
  - *> 25% increase in usable syngas (H_2 + CO) per unit mass of dry feedstock*
  - *> 35% decrease in overall Capex of the IBR*
  - *Decrease the OpEx of IBR so as to not exceed $2/GGE*
- *Challenges:*
  - *Design of Advanced Heater to replace existing electrical heaters with a small footprint in the steam reformer*
  - *Installation and integration of the Advanced Heater assembly with the steam reformer in narrow space between reformer vessel and support structure*
  - *Biomass preparation for PDU testing*

Process Operations Block Diagram



2 – Approach (Management)

- *Management approach:*
  - *Stage Gate method with a Steering Committee (one Executive from each team member) review at the first level and the DOE (and the Independent Engineers) review at the second level for Go/No Go decision*
  - *Critical success criteria or key technical achievements formulated for each stage so that the project meets or exceeds a minimum hurdle rate to proceed forward*
  - *Task based milestones to monitor progress*
- *Project structure:*
  - *Team comprising TRI, RTI and Velocys*
  - *TRI technical & Admin POCs for the DOE, Steering Committee, team member leads*
  - *Task Areas:*

TRI: PDU Integration, gasification, advanced heater – testing, validation, design, CFD, CPFD & ASPEN Plus simulations, FEA, scaleup, IP management plan

RTI: CO_2 removal & regeneration, H_2S/COS and HCN/NH_3 removal - testing, validation, design

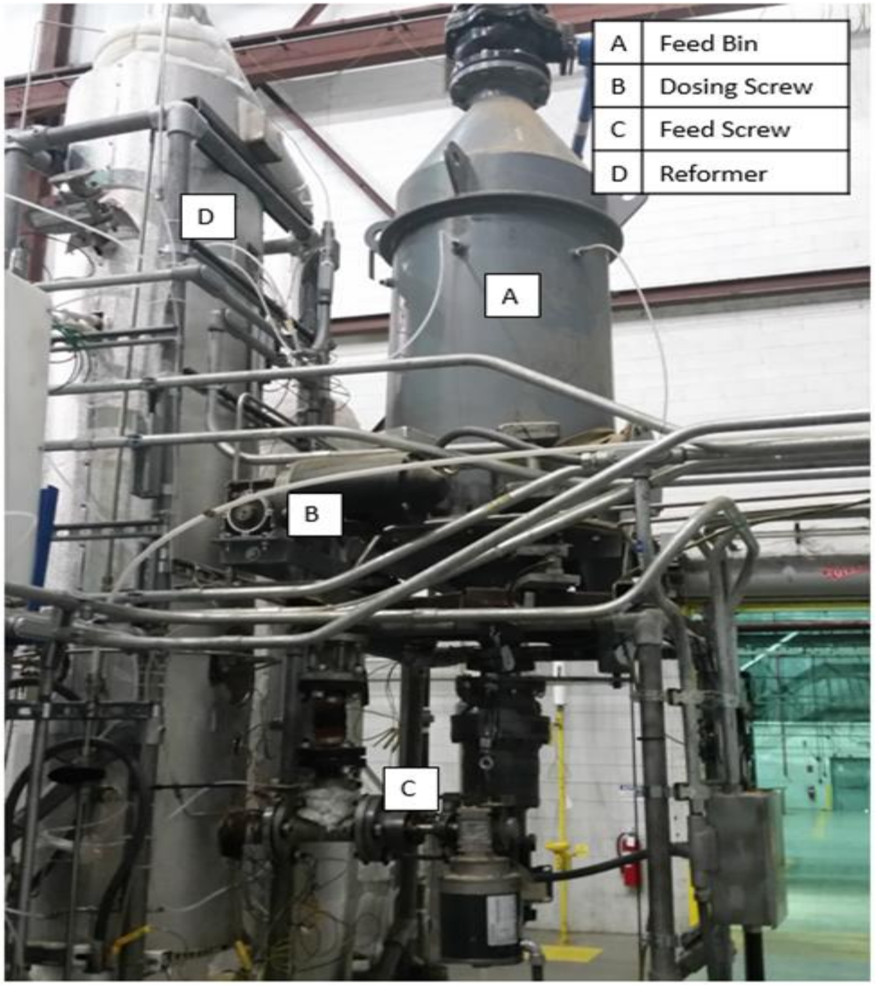
Velocys: Microchannel F-T synthesis & FTL upgrading - testing, validation, design

3 – Technical Accomplishments/ Progress/Results

- *Successful validation of relevant unit ops in BP1:*
  - *A total of 5 unit operations*
  - *31% increase in syngas (H_2+CO) per unit mass of biomass (target 25%)*
  - *Advanced heat exchanger heat flux and heat transfer coefficient superior to both conventional fire-tube and first generation pulsed heater*
  - *> 90% CO_2 capture efficiency (target 90%)*
  - *F-T CO single pass conversion > 60%*
  - *FTL hydrocracked without any adverse effect on the upgrading catalyst integrity and performance*

3 – Technical Accomplishments/ Progress/Results (cont'd)

Validation: *TRI Feedstock Test Reformer (FTR)*

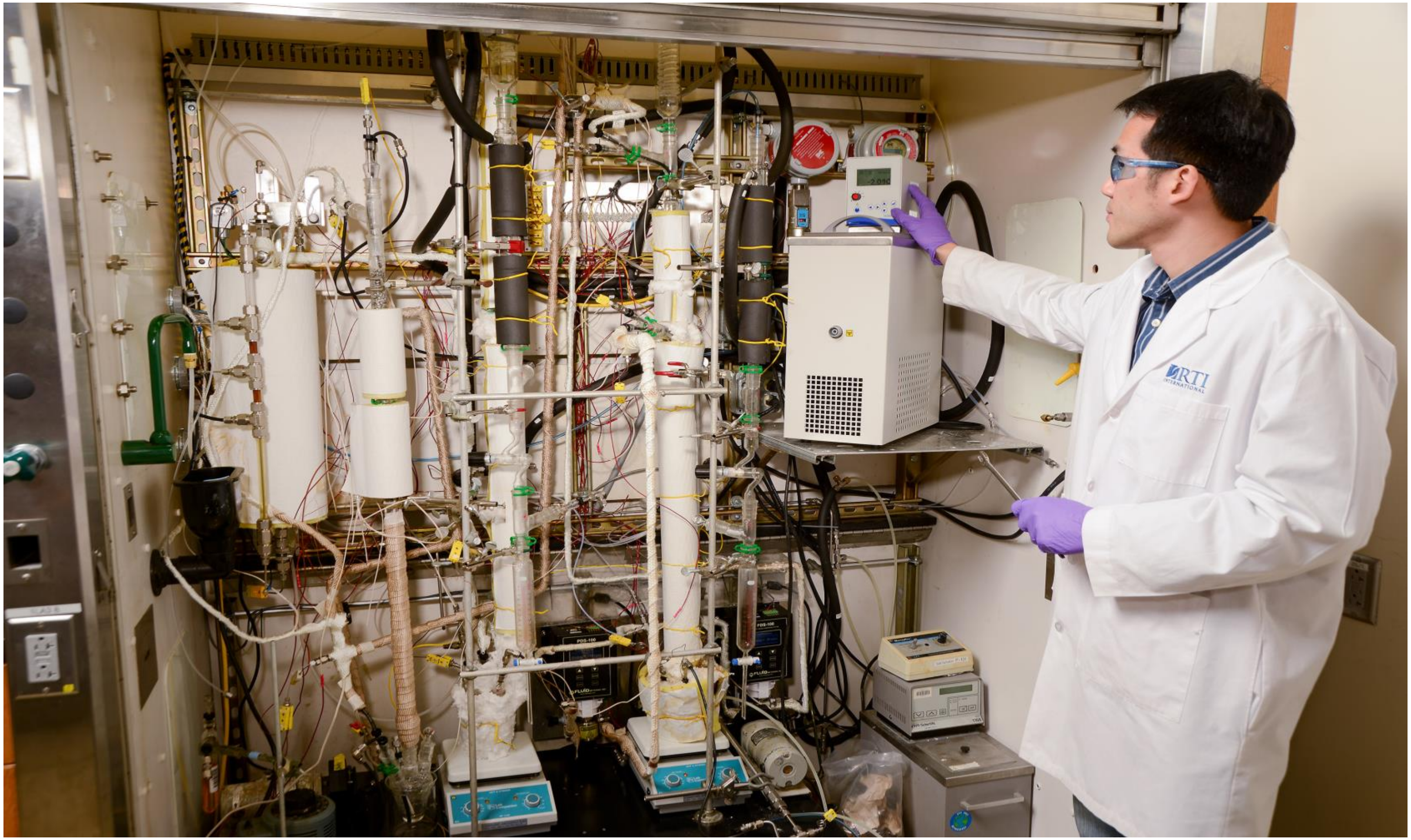


3 – Technical Accomplishments/ Progress/Results (cont'd)

Validation: *TRI Advanced Heater*

3 – Technical Accomplishments/ Progress/Results (cont'd)

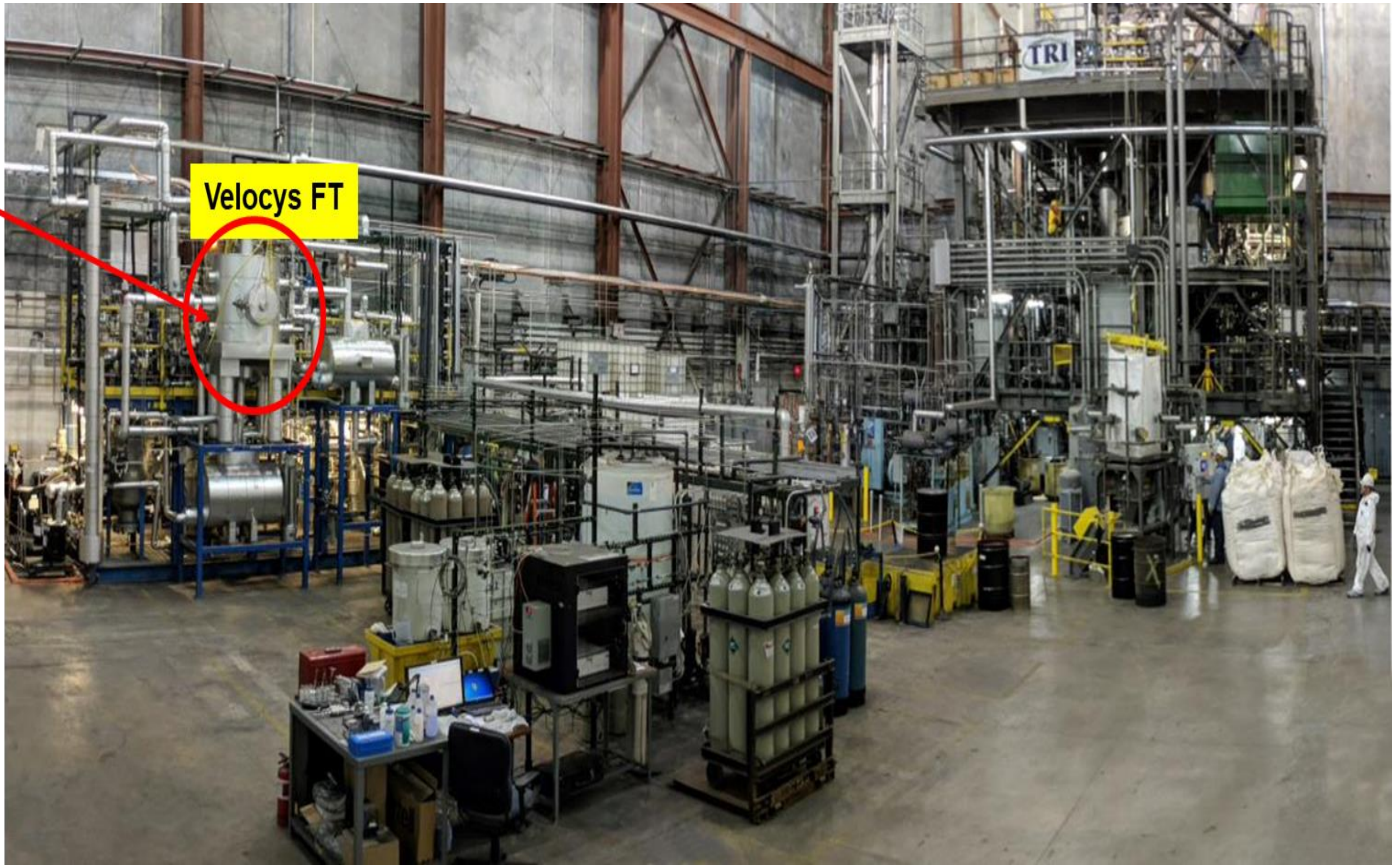
Validation: *RTI CO_2 Capture and Regeneration*



3 – Technical Accomplishments/ Progress/Results (cont’d)

Validation: *Velocys F-T Unit*

The insulated Velocys FT microchannel reactor



3 – Technical Accomplishments/ Progress/Results (cont'd)

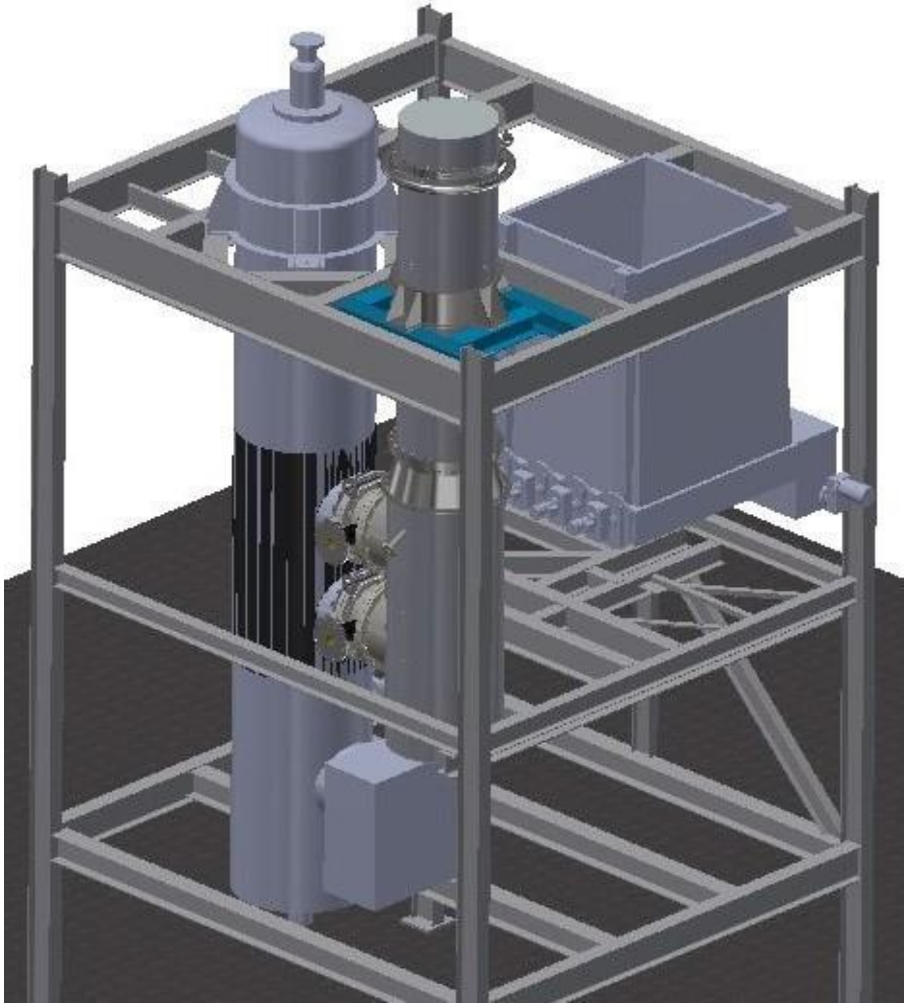
Validation: *RTI FTL Upgrading Unit*

3 – Technical Accomplishments/ Progress/Results (cont'd)

- *Status of BP2:*
  - *Advanced heater design for PDU integration completed*
  - *Advanced heater CFD modeling and validation ongoing*
  - *Advanced heater FEA ongoing*
  - *CO_2 removal and regeneration unit design completed*
  - *Microchannel F-T unit already integrated with the PDU and tested*
  - *NEPA documentation and permitting nearing completion*
  - *CPFD modeling and validation completed; proposed PDU system syngas (H_2+CO) output per unit mass of biomass exhibits 28% improvement over the first generation system (target 25%) – Go/No Go decision point*
  - *IP management plan nearing completion*

3 – Technical Accomplishments/ Progress/Results (cont'd)

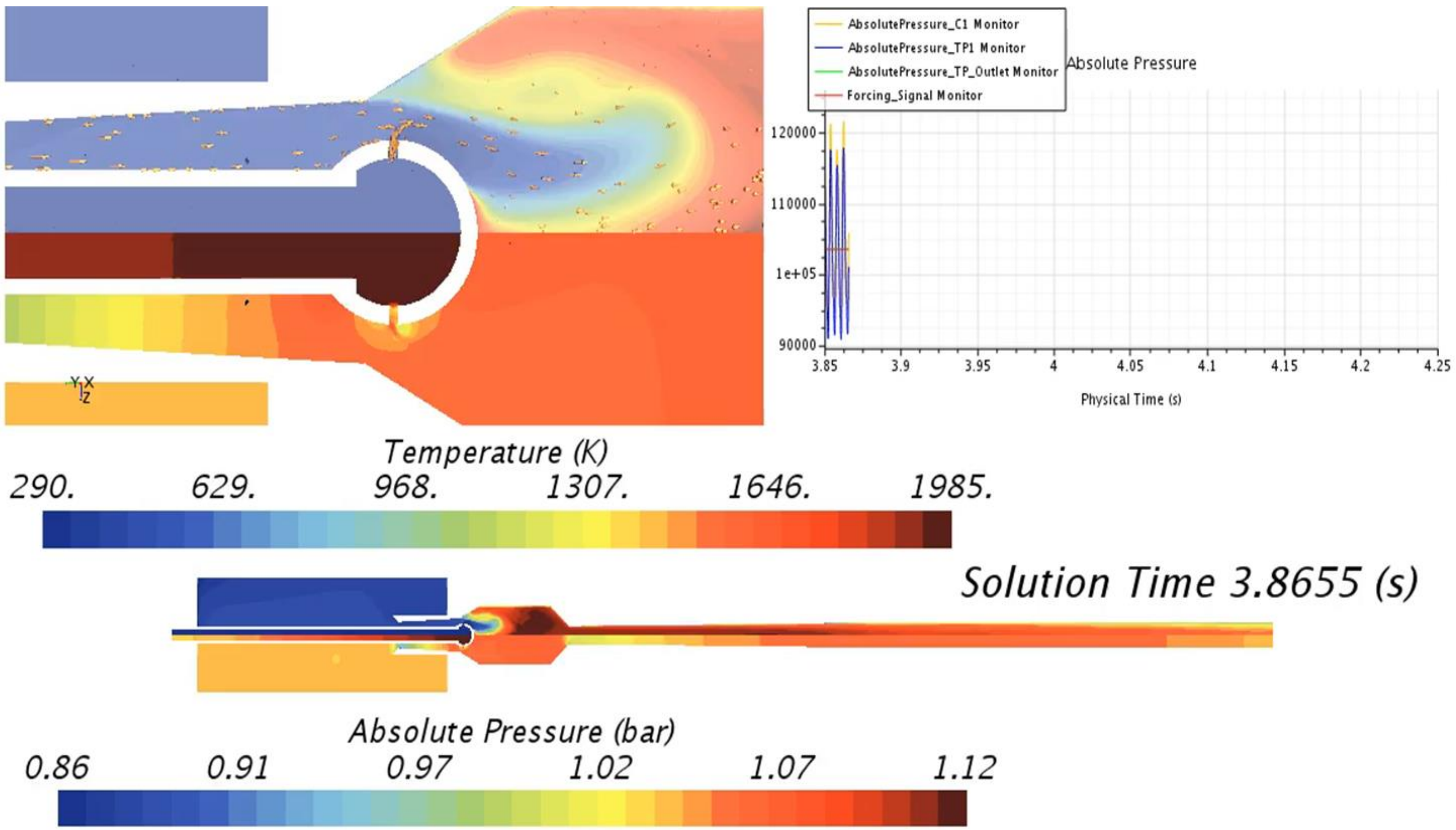
Advanced Heater Integration with the PDU Steam Reformer



3 – Technical Accomplishments/ Progress/Results (cont'd)

Advanced Heater CFD Simulation Summary:

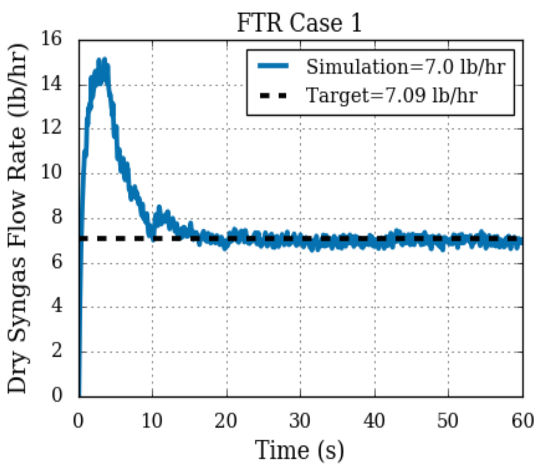
Phase 1A Test Unit Simulation and Validation



3 – Technical Accomplishments/ Progress/Results (cont’d)

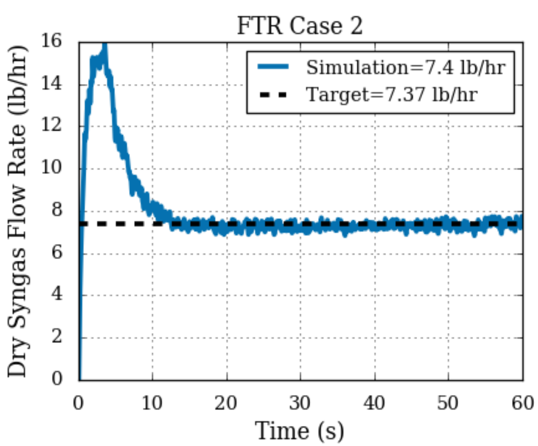
Steam Reformer CPFD Simulation Summary:

FTR Simulation & Validation



CO+H2

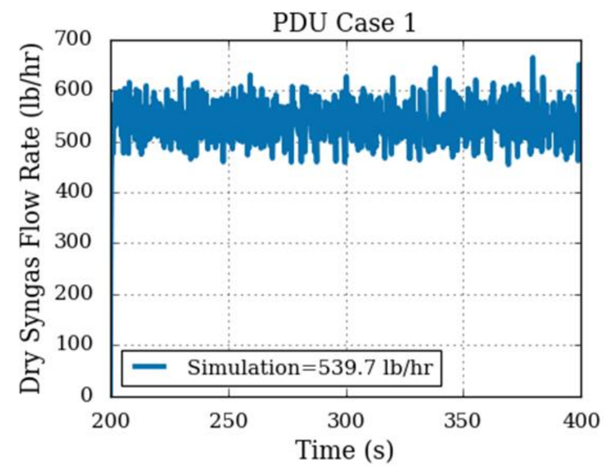
Test (kmol/s)	Sim (kmol/s)	%Error
1.91E-05	2.03E-05	6.23



CO+H2

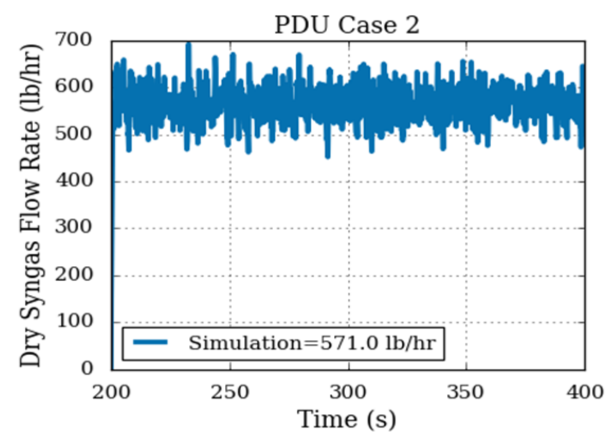
Test (kmol/s)	Sim (kmol/s)	%Error
2.51E-05	2.74E-05	8.94

PDU Simulation



CO+H2

Simulation (kmol/s)
1.93E-03



CO+H2

Simulation (kmol/s)
2.47E-03

4 – Relevance

- *Small scale IBRs with process intensification decrease biomass conversion costs and directly support BETO MYPP goals:*
  - *Enable sustainable, nationwide production of biofuels that are compatible with today's transportation infrastructure, can reduce greenhouse gas emissions relative to petroleum-derived fuels, and can displace a share of petroleum-derived fuels to reduce U.S. dependence on foreign oil*
  - *Encourage the creation of a new domestic bioenergy and bioproduct industry*
- *Addresses BETO's 2017 target of <$2/GGE biofuel cost*
- *Targets BETO's goal to validate biofuel production at pilot scale (>1 ton/day) by 2022*
- *Expected outputs – diesel, naphtha, biochar and BTEX; diesel is directly marketable, market analysis ongoing for other byproducts*
- *Project metrics, technical targets and marketing driven by TEA and LCA*
- *This small scale IBR facilitates lower biomass transportation costs and distributed, economical biofuel production*

5 – Future Work

- *Fabrication, Construction, PDU Integration, Commissioning, Trials, Scaleup and Engineering Assessment*
- *Upcoming key milestones:*
  - *Design and simulation results – Go/No Go decision (7/31/2019)*
  - *Feedstock selection and procurement*
  - *Equipment delivery to site*
  - *Installation of new equipment*
  - *Complete Commissioning; submit test plan – Go/No Go decision (Q1, FY2021)*
  - *Complete trial and shutdown*
  - *Compare PDU performance against targets*
  - *Issue Final Project Report (Q2, FY2022)*
- *Remaining budget ($919K) is sufficient to complete the remaining work in BP2*

Summary

1. Overview: *Second generation IBR for improved economics and wide scale deployment*
2. Approach*: Design, test and validate the high impact process intensification improvements to "first generation" IBR;*

    Critical success factors:

    > 25% increase in usable syngas (H_2 + CO) per unit mass of dry feedstock

    > 35% decrease in overall Capex of the IBR

    Decrease the OpEx of IBR so as to not exceed $2/GGE
3. Technical Accomplishments/Progress/Results: *Successful validation of 5 unit ops in BP1; Good progress on design, simulation and validation in BP2*
4. Relevance: *Directly supports BETO's MYPP, 2017 & 2022 goals*
5. Future work: *Construction, PDU Integration and demonstration*

Additional Slides

Responses to Previous Reviewers' Comments

- New project
- Successful initial process and data validation in BP1 resulted in a Go decision and approval to proceed into BP2
- Surpassed the target for (H_2+CO) yield increase

Publications, Patents, Presentations, Awards, and Commercialization

- No publications, patents, awards, and presentations have resulted from work on this project
- Commercialization of this technology will benefit from the maturation of large scale IBRs

Project Scope Change Table

Scope Changes	Date	Logic / Reasoning	Approval / Rejection Date
BP1			
- Scope Change 1	4/2017	Validation of FTL upgrading was added to milestone 1	Approved 12/2017
- Scope Change 2	4/2017	Instead of standalone Velocys lab-scale microchannel FT reactor validation, validation of pilot scale Velocys microchannel FT reactor integrated with the TRI PDU was added to milestone 1	Approved 10/2017

Risk Registry Table

	Risk Identified			Mitigation Strategy		Current Status
Risk ID	**Process Step**	**Risk Description**	**Severity (High/ Med/Low)**	**Mitigation Response**	**Planned Action Date**	**Active/ Closed**
TRI Indirectly heated steam reforming						
1	Modified steam reforming process	Syngas (H_2+CO) yield increase	High	Validation trial	10/2017	Successful; closed
2	Advanced heater	Heat transfer effectiveness	High	Validation trial	10/2017	Successful; closed
3	Scale-up of 1 Scale-up of 2	Performance	Medium High	CPFD CFD simulation	1/2019 Ongoing	Successful; Closed Active
4	PDU Integration	Brownfield installation	Medium	3D Modeling	Ongoing	Active
RTI CO_2 capture and regeneration						
1	From syngas	> 90% capture	High	Validation trial	10/2017	Successful; closed
2	PDU Integration	Brownfield installation	Medium	3D Modeling	Ongoing	Active

Risk Registry Table (cont'd)

	Risk Identified				Mitigation Strategy		Current Status
Risk ID	Process Step	Risk Description	Severity (High/ Med/Low)	Mitigation Response	Planned Action Date	Active/ Closed
Velocys Microchannel FT						
1	FT synthesis	Performance	Medium	Validation trial	3/2018	Successful; closed
2	PDU Integration	Brownfield installation	Medium	Installed and operated	3/2018	Successful; closed
FT upgrading						
1	Diesel and Naphtha	Catalyst integrity and performance	Medium	Validation trial	3/2018	Successful; closed