Flue Gas Water Vapor Latent Heat Recovery for Pressurized Oxy-Combustion

Project DE-FE0025350
NETL Program Manager: Steve Markovich
DOE-NETL CO2 Capture Technology Meeting
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Rick Knight – Institute Engineer
Gas Technology Institute

Project Overview

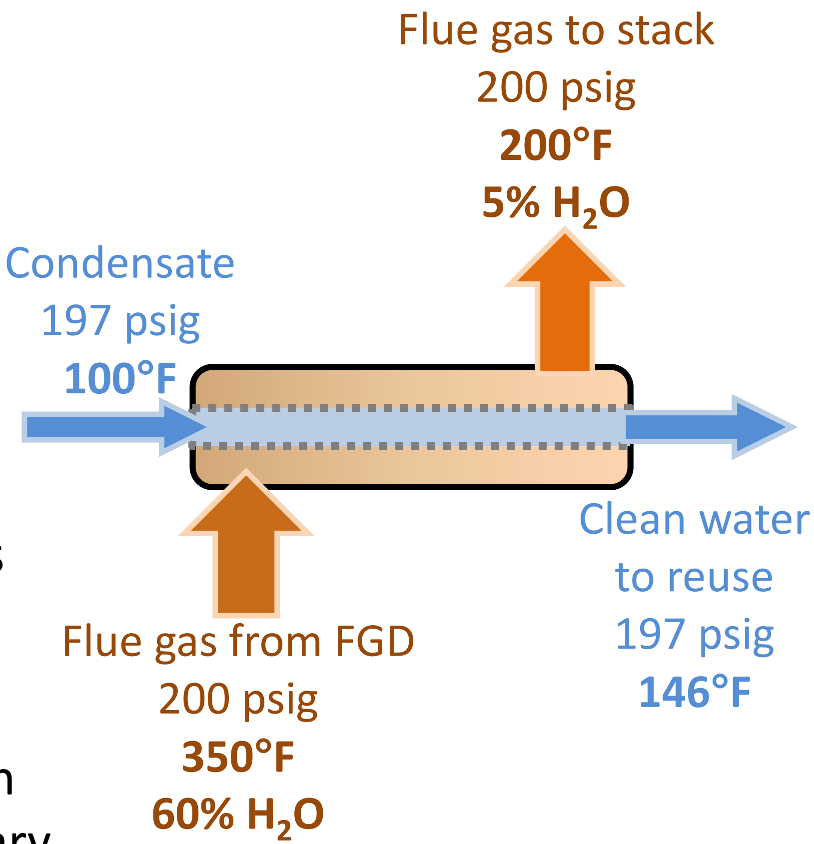
- Funding: $2,648,945
  - DOE = $1,999,795. Cost share = $649,150 (24.5%)
- Performance dates:
  - Phase I: Sep 1 2015 – Aug 31 2016
  - Phase II: Sep 1 2016 – Aug 31 2017
- Participants:
  - Gas Technology Institute (lead)
  - Media & Process Technology
  - Florida International University
  - SmartBurn LLC

Project Overview

- Overall Project Objectives
  - Facilitate energy and water recovery to improve the efficiency of pressurized oxy-coal power boilers
  - Design, build, and test a high-pressure modular version of the Transport Membrane Condenser (TMC) at pilot scale to evaluate its performance and analyze the results for future commercial-scale power plants.

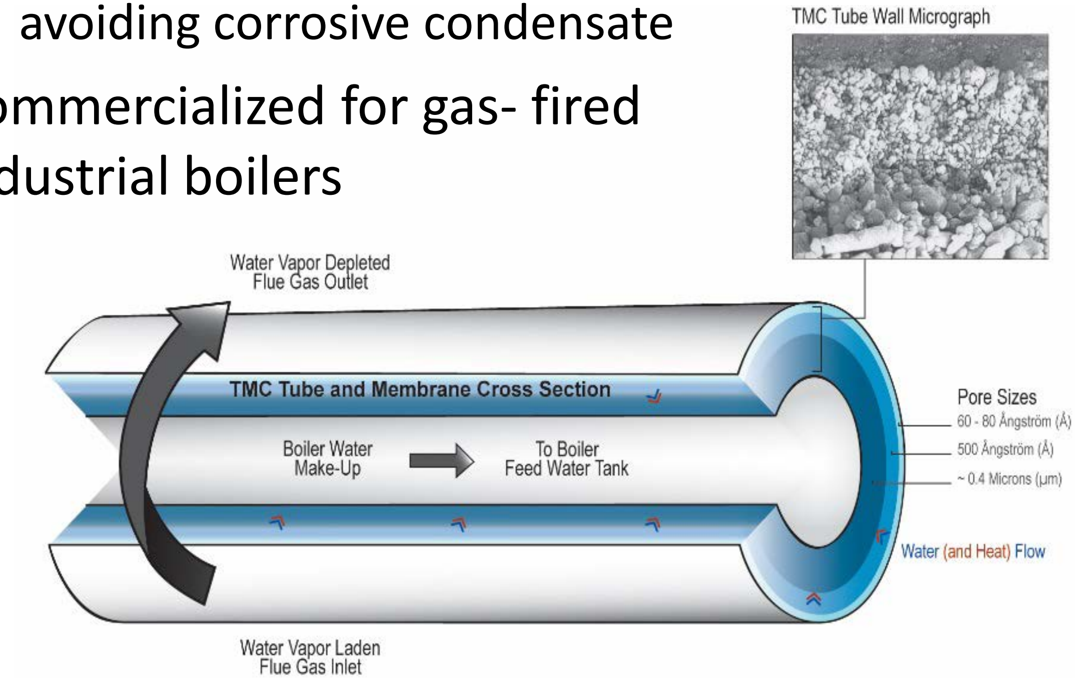
Technology Background

- Concept: recover water of combustion along with latent heat
- Investigated 4 modes of separation:
  - Molecular Sieving
  - Knudsen diffusion
  - Surface diffusion
  - Capillary condensation
- Working mode of porous membrane is critical for water vapor separation *and* transport
  - ✓ High permeate flux and high separation ratio could <u>only</u> be achieved in a <u>capillary condensation mode</u> for water vapor.



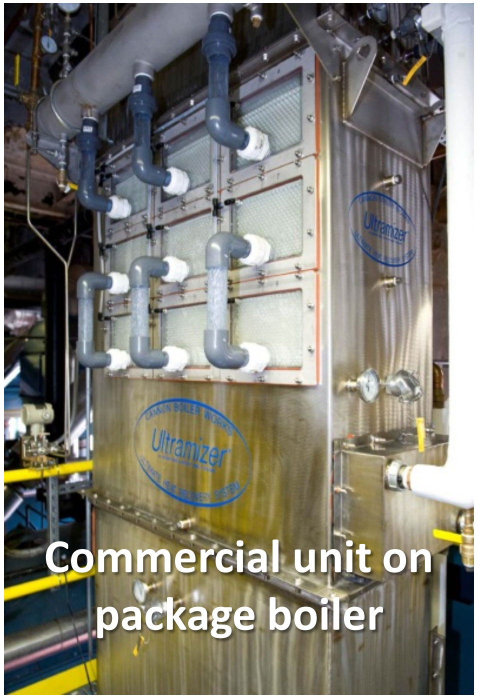
Technology Background

- GTI developed Transport Membrane Condenser (TMC) technology
- Nanoporous ceramic membrane selectively recovers water vapor and latent heat from natural gas combustion flue gases
  - Increases boiler efficiency and saves water, avoiding corrosive condensate
- Commercialized for gas- fired industrial boilers

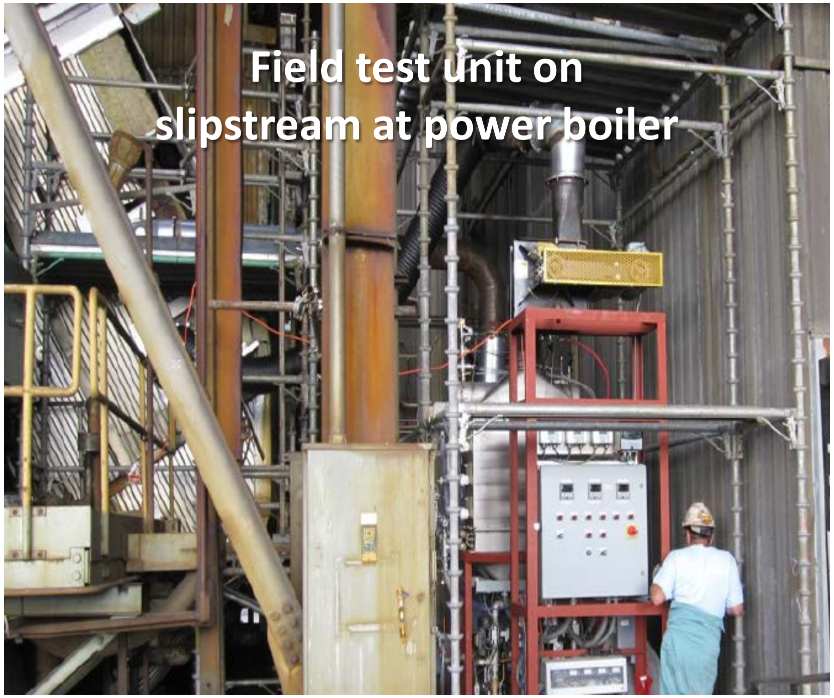


Technology Background

- Package boilers (gas- and oil-fired)
- Non-boiler industrial applications (e.g., commercial laundry)
- Existing power plants (slipstream from coal-fired power boiler)



Commercial unit on package boiler



Field test unit on slipstream at power boiler

Technology Background

❑ ADVANTAGES

- ✓ Latent heat recovery can boost power generation efficiency of oxy-coal boiler by 14%
- ✓ TMC can recover clean water from flue gas equal to 2.0% of steam demand
- ✓ No boiler modifications required
- ✓ Reduced dew point of flue gas

❑ CHALLENGES

- ✓ Durability of TMC in flue gas with coal-derived contaminants (particulates, SO_2, and NO_x)
- ✓ Integrity of ceramic multi-tube sealing in pressurized TMC operation
- ✓ Controllability and performance

Approach/Scope

- Experimental design
  - Multiple TMC assemblies housed in pressure vessels, connected in parallel and/or series
- Work plan
  - Develop and build high-pressure modular version of the TMC
  - Install TMC skid at GTI's Flex Fuel Gasification Facility
  - Gasify PRB coal, combust and condition syngas to simulate exhaust from pressurized slurry-fed oxy-coal combustion with FGD at 1-3 MW_{th} scale
  - Test TMC in combinations of series and parallel modes
- Success criteria
  - TMC performance conforms to model predictions
  - TMC meets expectations for controllability and durability

Approach/Scope

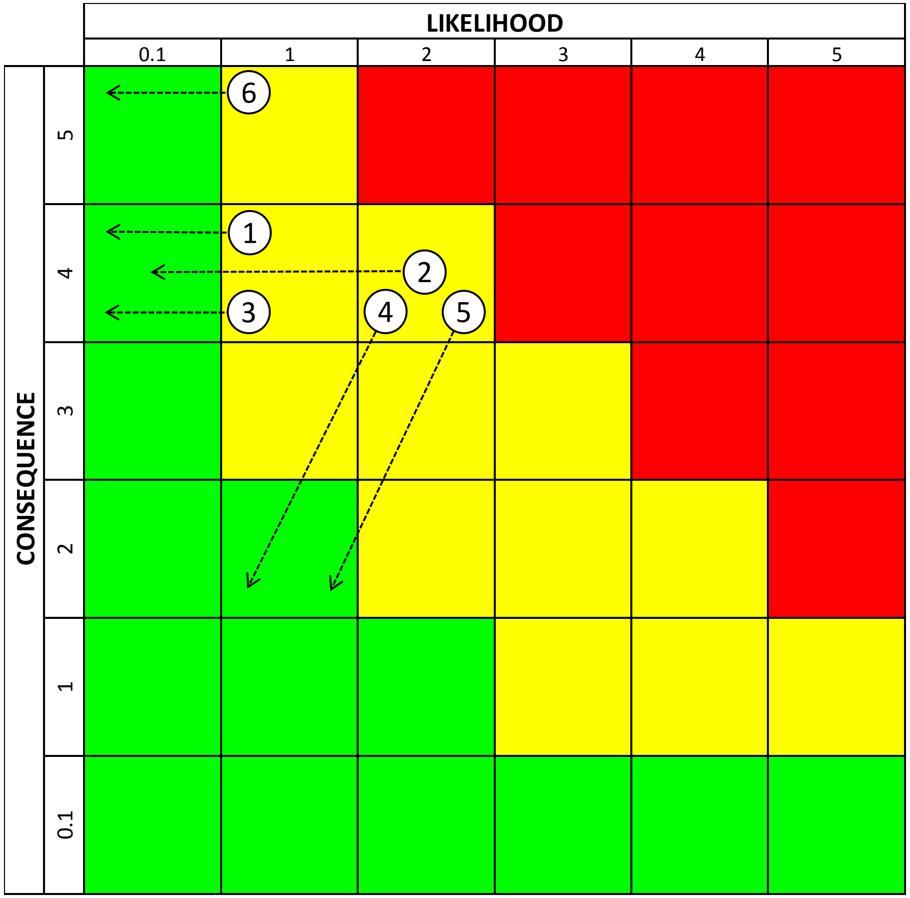
		BUDGET PERIOD I													BUDGET PERIOD II											
		2015				2016												2017								
Tasks		S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
0.0 Pre-Award Costs																										
1.0 Project Management and Planning				*M1*										*M2*									*M4*			
2.0 Process Modeling and Design Evaluation																										
2.1 Process Modeling for System Design																										
2.2 CFD Simulation to Define TMC Design Parameters																										
3.0 TMC Unit Design, Fabrication, and Assembly for High Pressure																										
3.1 Spaced Tube Bundles Design, Fabrication and Testing																										
3.2 High Pressure Bundle Housing Design, Fabrication and Testing																										
3.3 TMC Unit Assembly and System Control Setup																										
4.0 Pressurized Oxy-Coal Pilot Test System Preparation																										
4.1 Feedstocks and Raw Material Preparation																										
4.2 Test System Modifications																										
4.3 Test Plan																										
5.0 Overall Test System Installation and Shakedown																										
5.1 TMC System Installation and Control Integration with Oxy-Coal Test Rig														*M3*												
5.2 System Shakedown																										
6.0 System Performance Testing for Latent Heat Recovery																										
6.1 TMC Performance Test #1																										
6.2 TMC Performance Test #2																										
6.3 Result Summary and Future Development Directions																										
7.0 Scale-Up and Integration Evaluation for Commercial Scale																										
ENTIRE PROJECT																										

Milestones:
M1 = updated PMP
M2 = Budget Period I Report
M3 = Test Readiness Report
M4 = Final Project Report

Approach/Scope

RISK MITIGATION

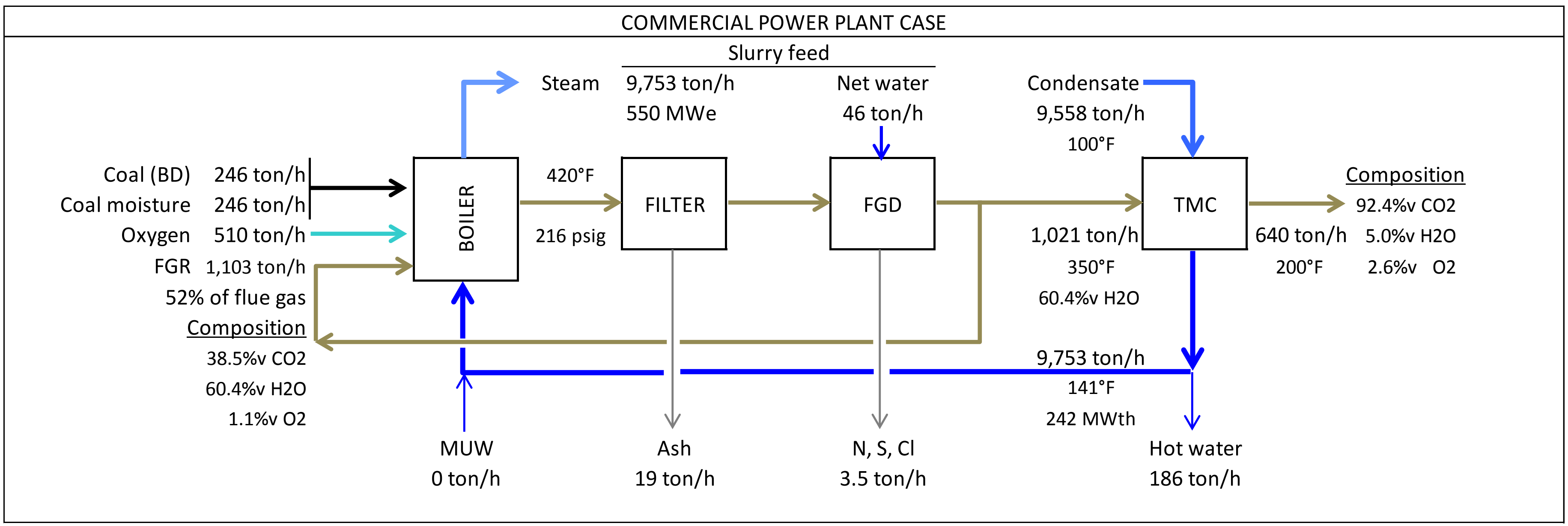
1. Pilot plant availability
   - Schedule and coordinate with other tests
2. Subcontractor/vendor delays
   - Formalize deadlines, biweekly update
3. Labor cost exceeds estimates
   - Forecasting, contract labor
4. Steam supply
   - Dedicated steam generator for syngas burner
5. Tar reformer untested as burner
   - HP burner design experience, earlier start
6. TMC pressure seal & control
   - New high-pressure seal design, delta-P control



Progress & Current Status

Task 2: Process Modeling and Design Evaluation

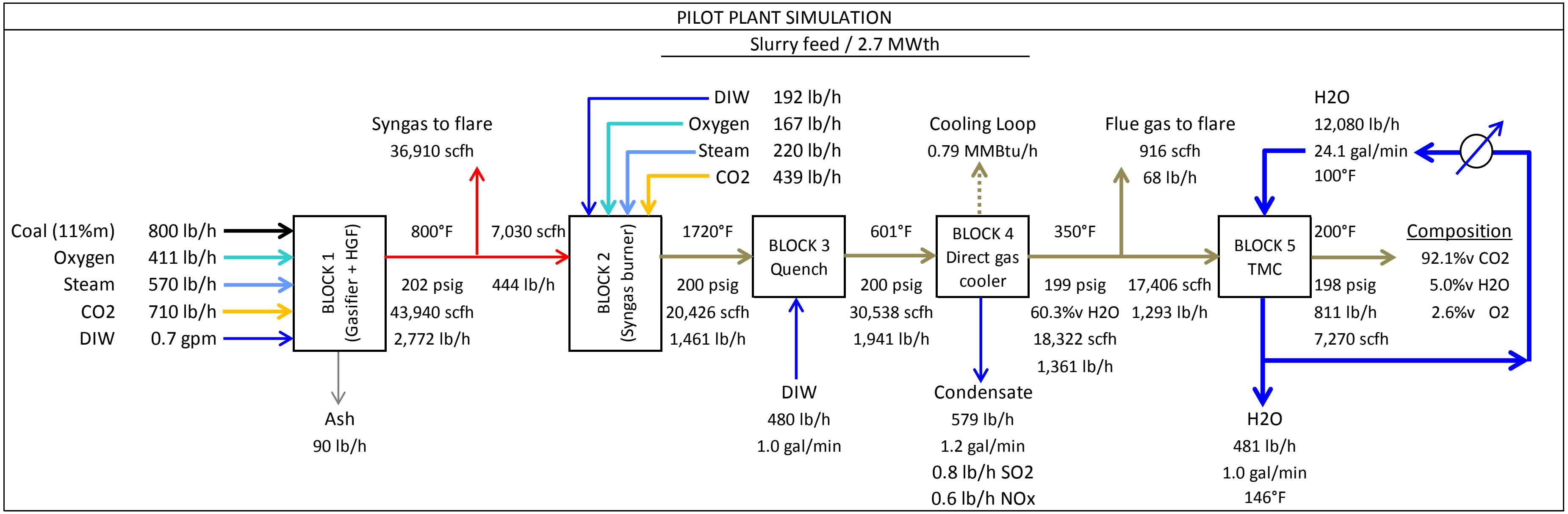
- Task 2.1: Process Modeling for System Design and Operation
  - Model for commercial reference case is a 550-MW_e slurry feed oxy-coal boiler using PRB coal with 50% moisture
  - Flue gas is recirculated from downstream of FGD



Progress & Current Status

Task 2: Process Modeling and Design Evaluation

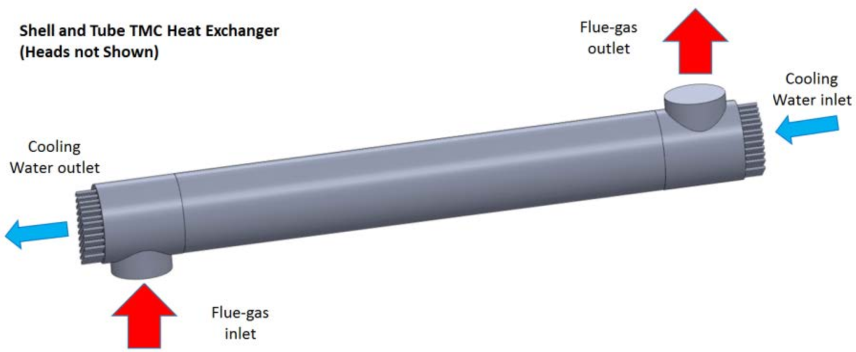
- Task 2.1: Process Modeling for System Design and Operation
  - Developed and updated model for 2.7-MW_{th} pilot simulation of commercial case
  - Coal is gasified, syngas filtered, and slipstream combusted with oxygen, CO_2, water, and steam to obtain conditioned flue gas for TMC testing
  - Portion of TMC water is recycled and cooled to simulate plant water supply

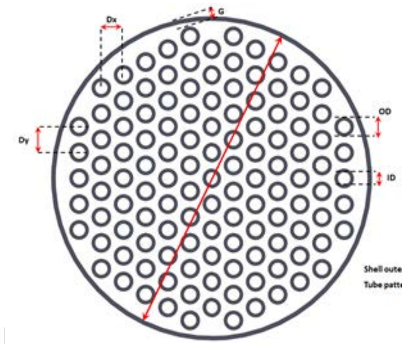


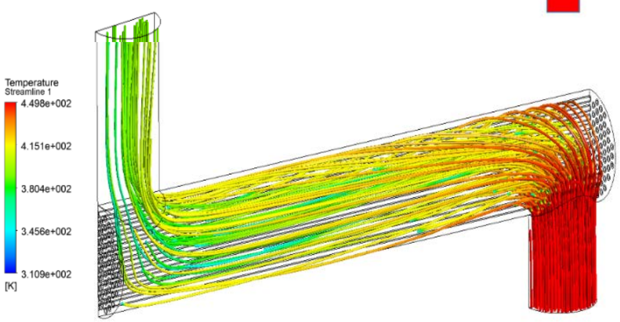
Progress & current status

Task 2: Process Modeling and Design Evaluation

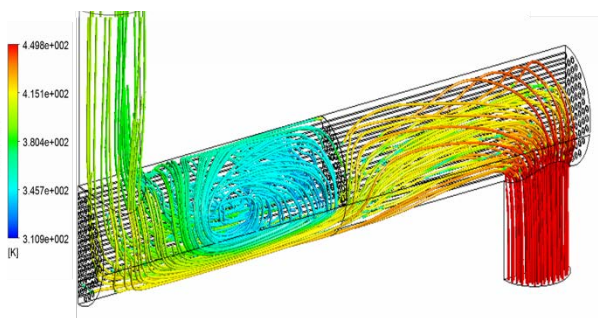
- Task 2.2: CFD Simulation to Define TMC Design Parameters
  - Single TMC module CFD study for different tube arrangement effect
  - Baffle effect has been studied, and the 3-baffle configuration shows optimum heat and mass transfer



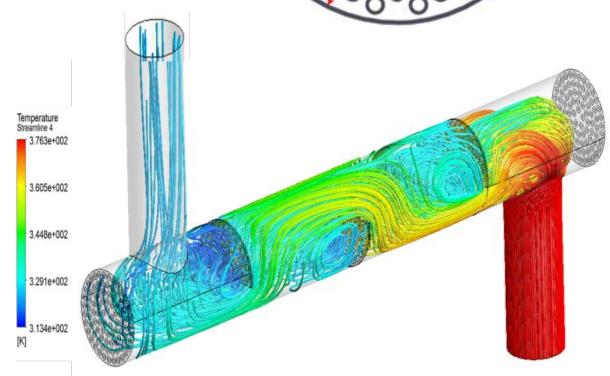




No-baffle configuration



1-baffle configuration

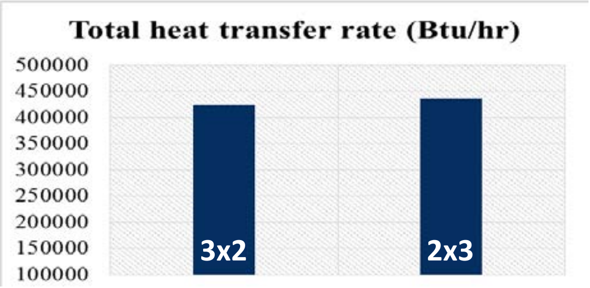


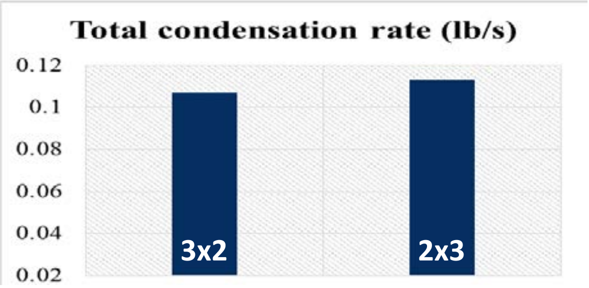
3-baffle configuration

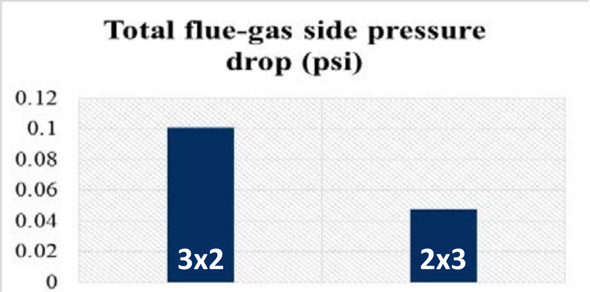
Progress & current status

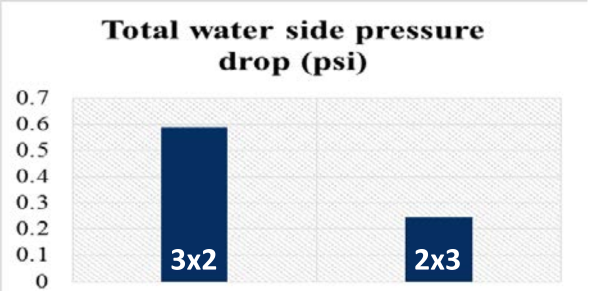
Task 2: Process Modeling and Design Evaluation

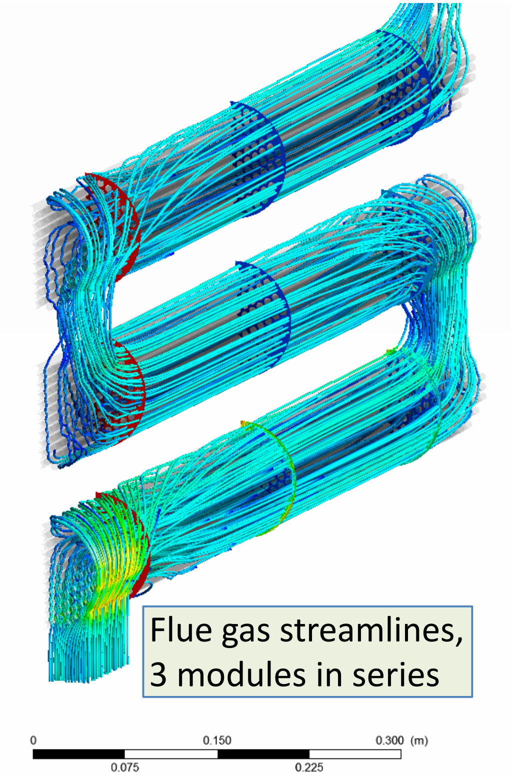
- Task 2.2: CFD Simulation to Define TMC Design Parameters
  - Six TMC modules arranged into different series and parallel configurations based on flue gas flow
    - 3x2 (3 in series, 2 parallel sets)
    - 2x3 (2 in series, 3 parallel sets)











Flue gas streamlines, 3 modules in series

Progress & current status

Task 3: TMC Unit Design, Fabrication, & Assembly for High Pressure

- ❑ Task 3.1: Spaced tube bundles design, fabrication, and testing

Dual Ended Bundles (2" Prototypes)

- ✓ Prepared several 2"-diameter spaced dual ended bundles
- ✓ Completed 2" bundle thermal cycling in a standard stainless steel module; no thermal mismatch problems encountered
- ✓ Tested at 200°C in 200-psig saturated steam

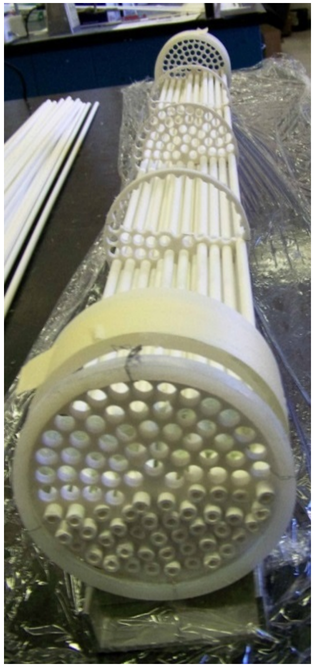
Dual Ended Bundles (4" Pilot Scale)

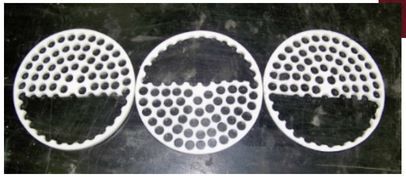
- ✓ Prepared first pilot scale 4"-diameter spaced dual ended bundle
- ✓ Completed 4" bundle thermal cycling in a standard stainless steel module; no thermal mismatch problems encountered
- ✓ Adapted Teflon baffles for enhancing flue gas side heat transfer

Next Phase

- ✓ Prepare six 4"-diameter pilot scale bundles

4" Diameter x 36" Length Bundle w/ Teflon Baffles





Progress & current status

Task 3: TMC Unit Design, Fabrication, & Assembly for High Pressure

- Task 3.2: High-Pressure Bundle Housing Design, Fabrication, and Testing

Standard "Rigid" Header Design

- ✓ Thermal cycling of a 2" x 36" glass reinforced epoxy potted bundle to 250°C with no failure of the tubes, potting, or seal
- ✓ Hydrothermal cycling of the 2" bundle at 200°C in 200 psig steam

Next Phase

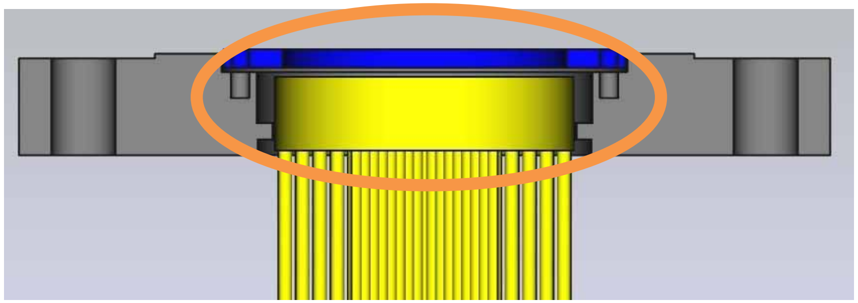
- ➢ Six pilot scale modules under construction.

Floating Header Design

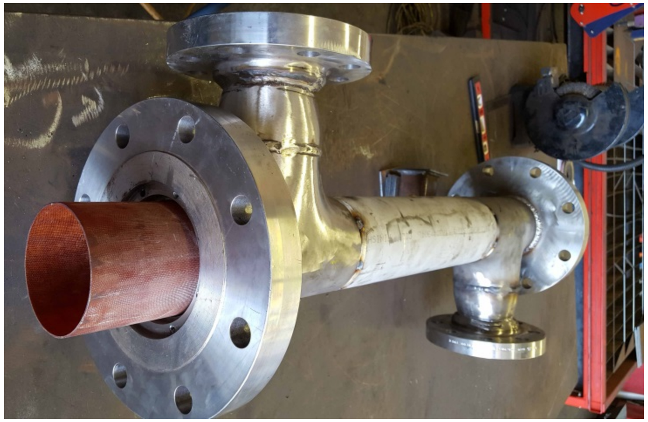
- ➢ Driver: thermal mismatch between stainless steel housing and ceramic tubes yields a potential 1/8" expansion difference at the application temperature
- ✓ On hold following successful testing of "rigid" header module

Rigid Header Module

(Sealing fixture integral part of the housing)



Pilot Scale Testing Module



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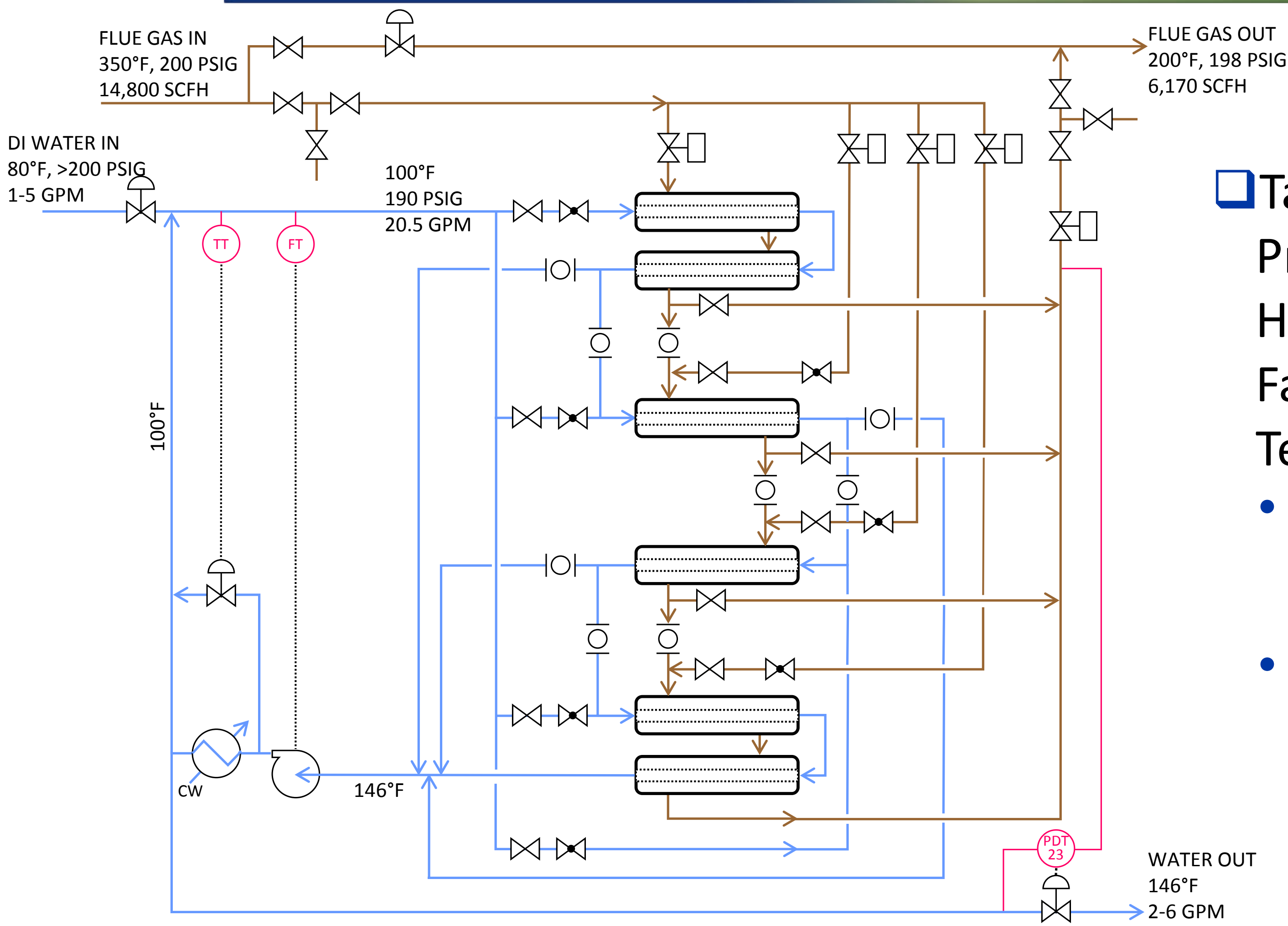
Progress & Current Status

Task 3: TMC Unit Design, Fabrication, & Assembly for High Pressure



- ❑ Task 3.2: High-Pressure Bundle Housing Design, Fabrication, and Testing
  - CFD simulation guided flexible layout
  - Two configurations for pilot testing

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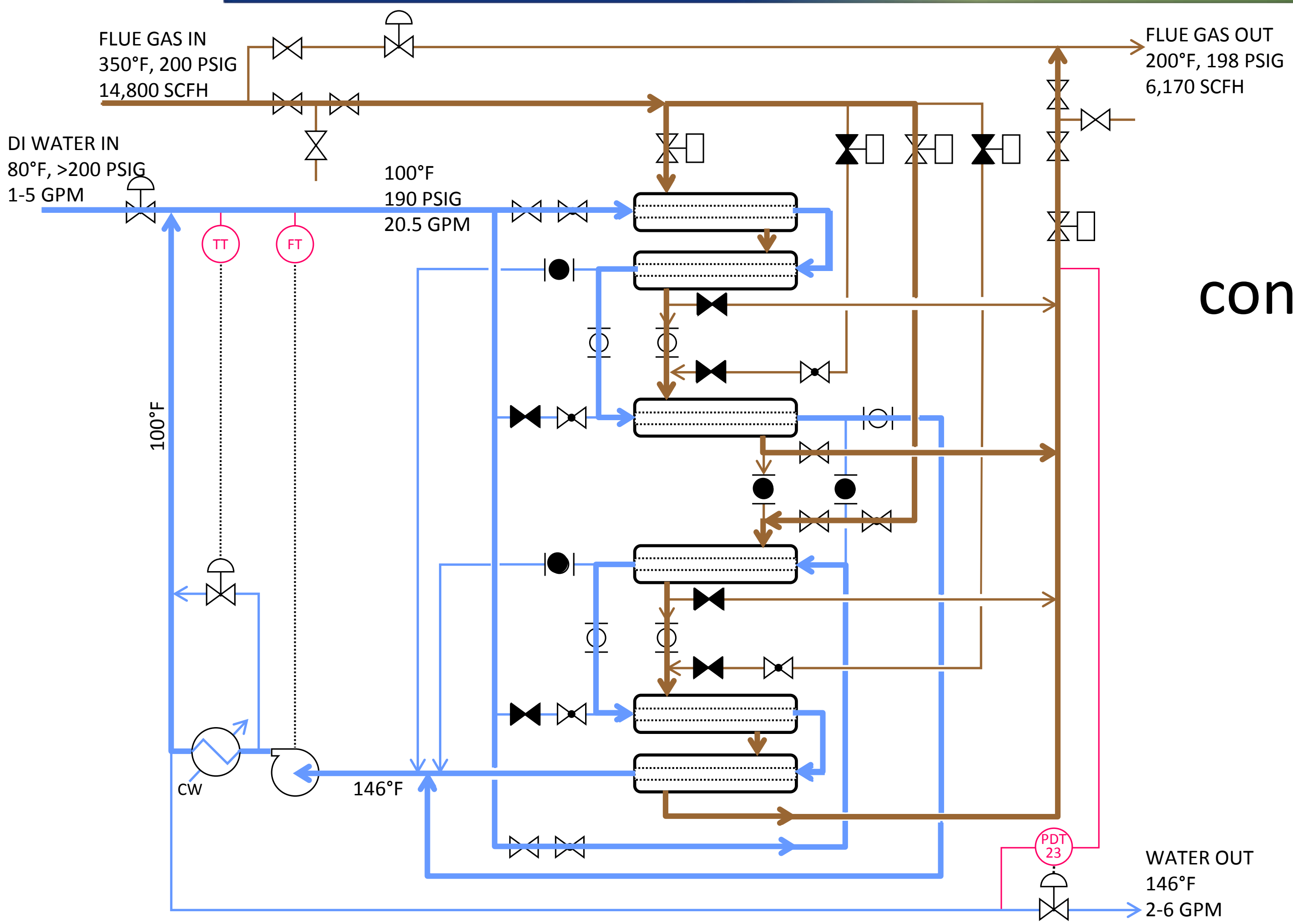
Progress & Current Status

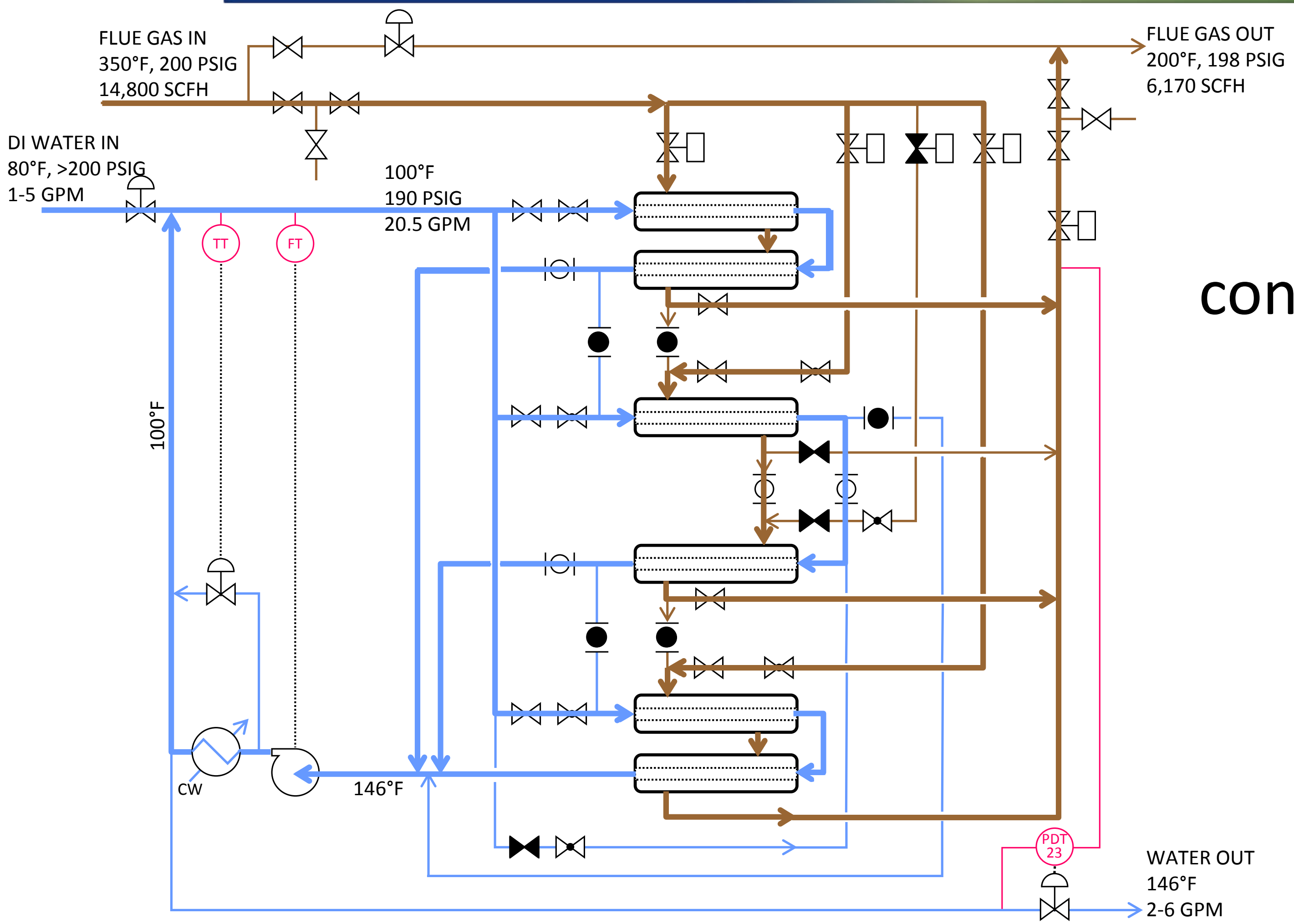
Task 3: TMC Unit Design, Fabrication, & Assembly for High Pressure



3×2 configuration

Progress & Current Status

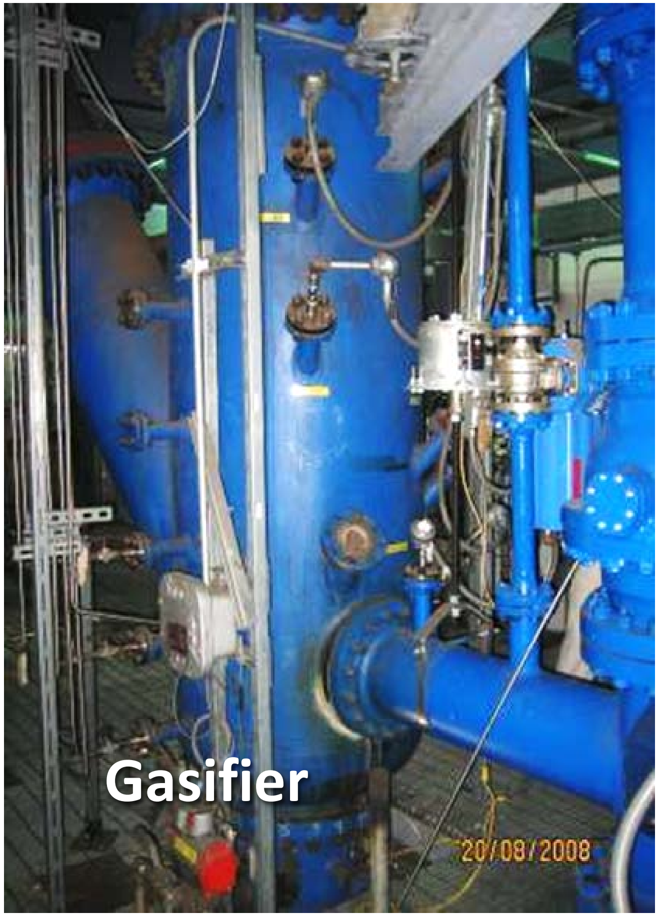
Task 3: TMC Unit Design, Fabrication, & Assembly for High Pressure



2×3
configuration

Progress & Current Status

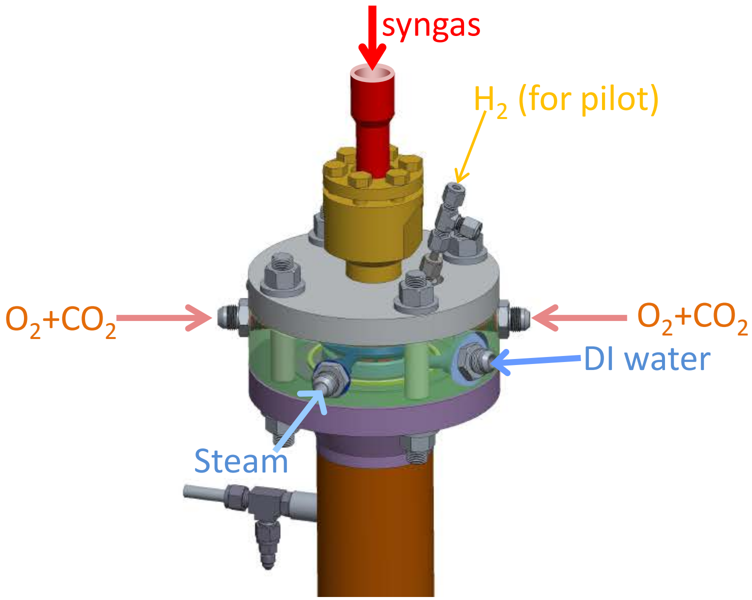
Task 4: Pressurized Oxy-Coal Pilot System Test Preparation

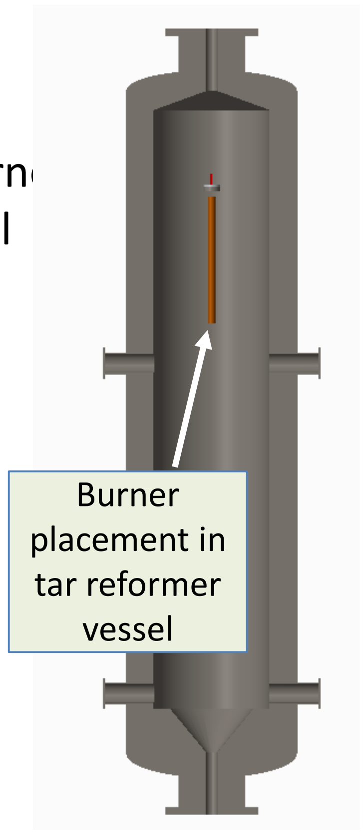


Progress & Current Status

Task 4: Pressurized Oxy-Coal Pilot System Test Preparation

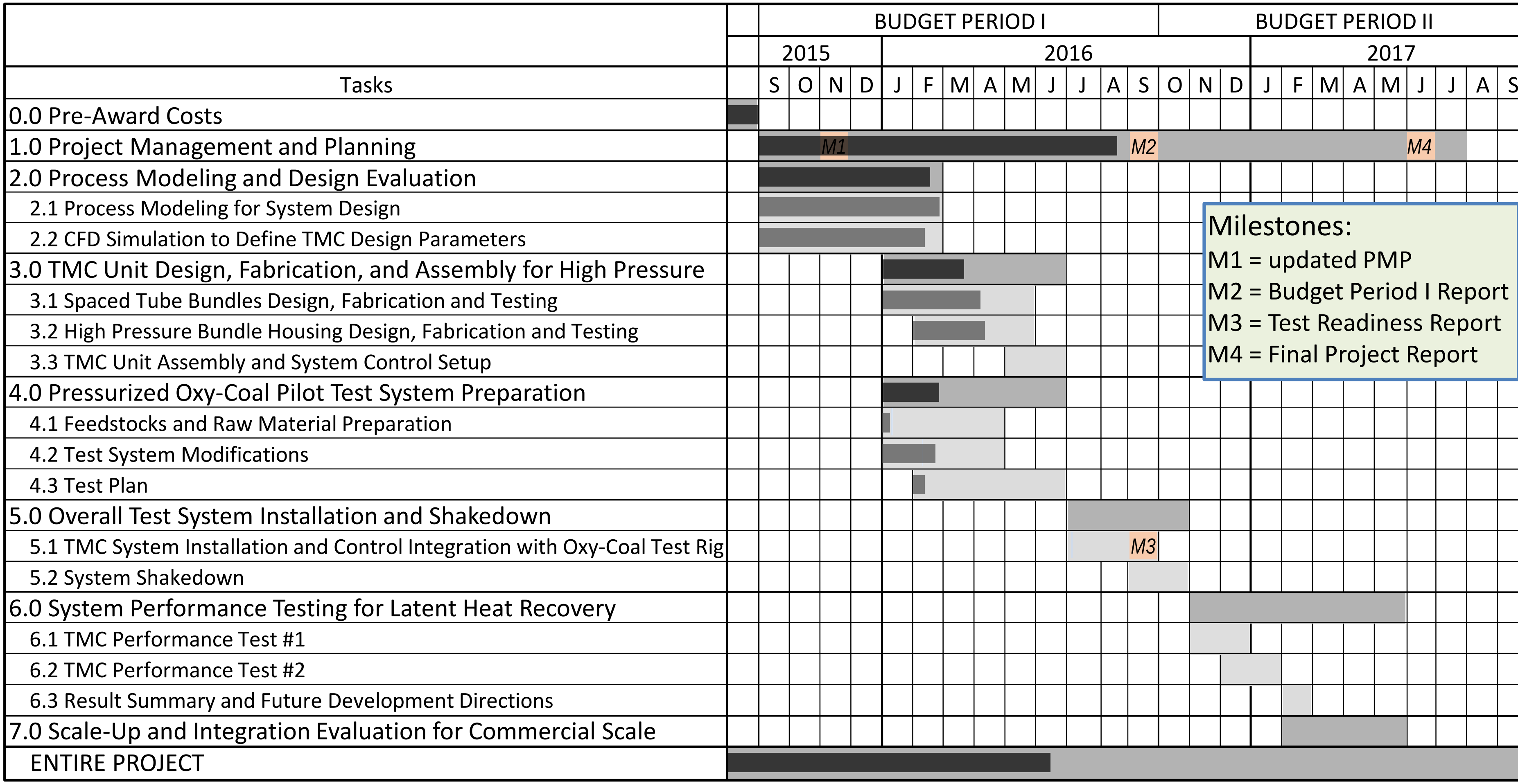
- Task 4.2: Test system modifications
  - Completed design of coal feeding lift line modification
  - Completed design and BOM for syngas burner integrated with existing tar reformer vessel
  - Burner components in fabrication





Progress & Current Status

Schedule and Earned Value update



Progress & Current Status

Risk management

RISK MITIGATION

1. Pilot plant availability
   - Schedule and coordinate with other tests
2. Subcontractor/vendor delays
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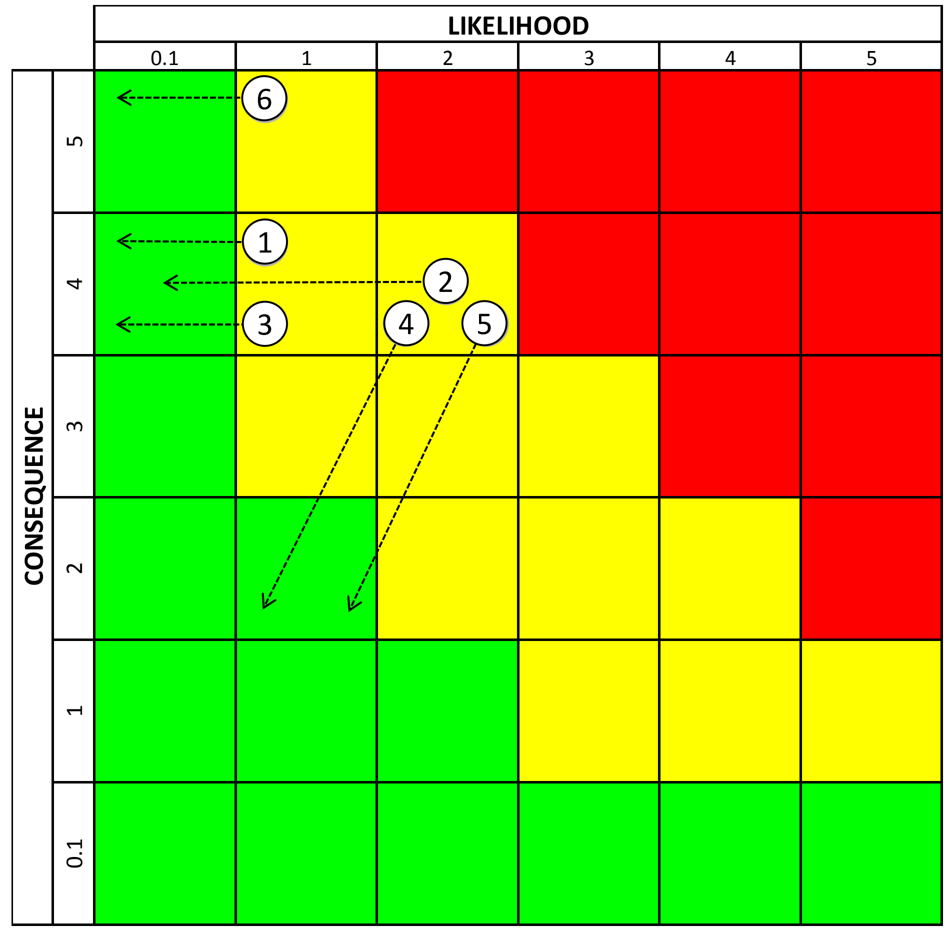

Progress & Current Status

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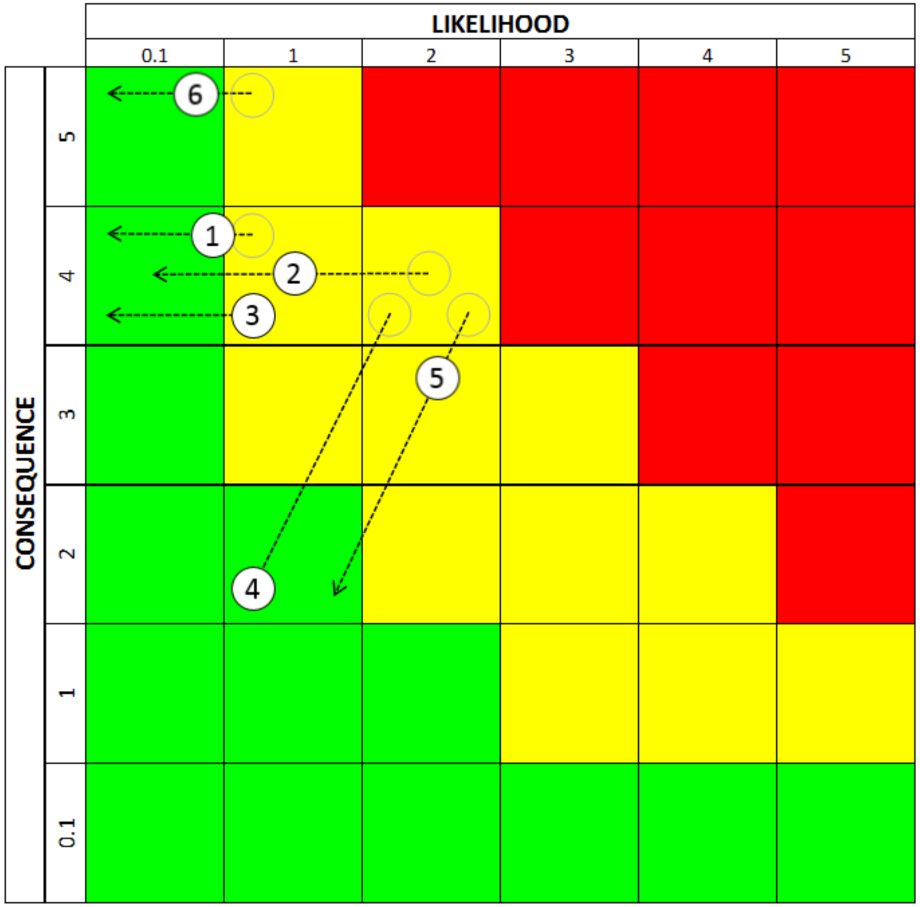

Plans for Future

Testing, development, commercialization

- Testing (this project)
  - We plan to test each of two TMC configurations for at least 24 hours at steady state conditions
  - Key variables will be TMC inlet water flow rate and temperature
  - Test results will be used to validate CFD modeling, which can then be applied to evaluate more configurations and operating modes
- Future development
  - Cost optimization for control and operation
  - Cost optimization for membrane module manufacture
  - Larger scale pilot study to evaluate commercial application

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Acknowledgment

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Media & Process Technology

Smartburn LLC

Thanks!

Questions?