Development of a Thin Film Primary Surface Heat Exchanger for Advanced Power Cycles

DE-FE0024104 Kickoff Meeting

Oct 10, 2014

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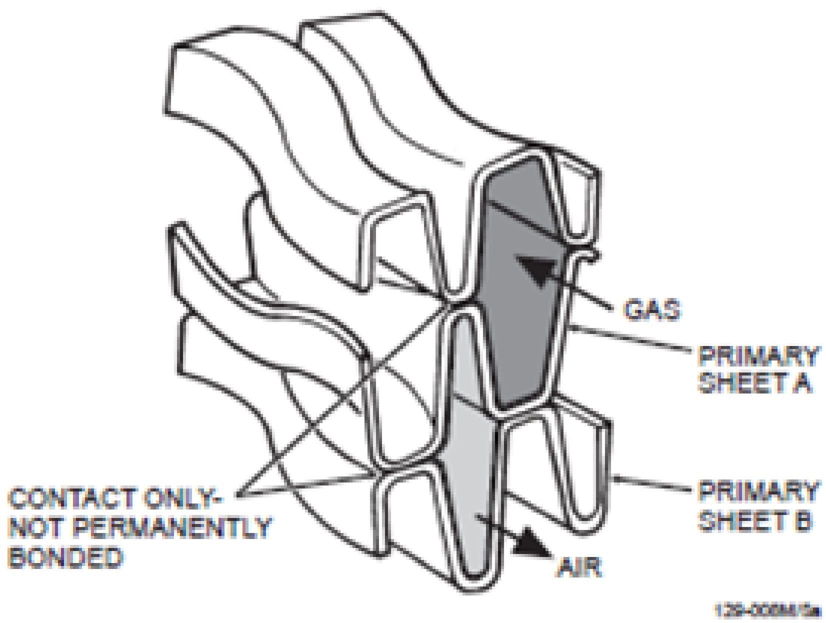


Primary Surface Sheets

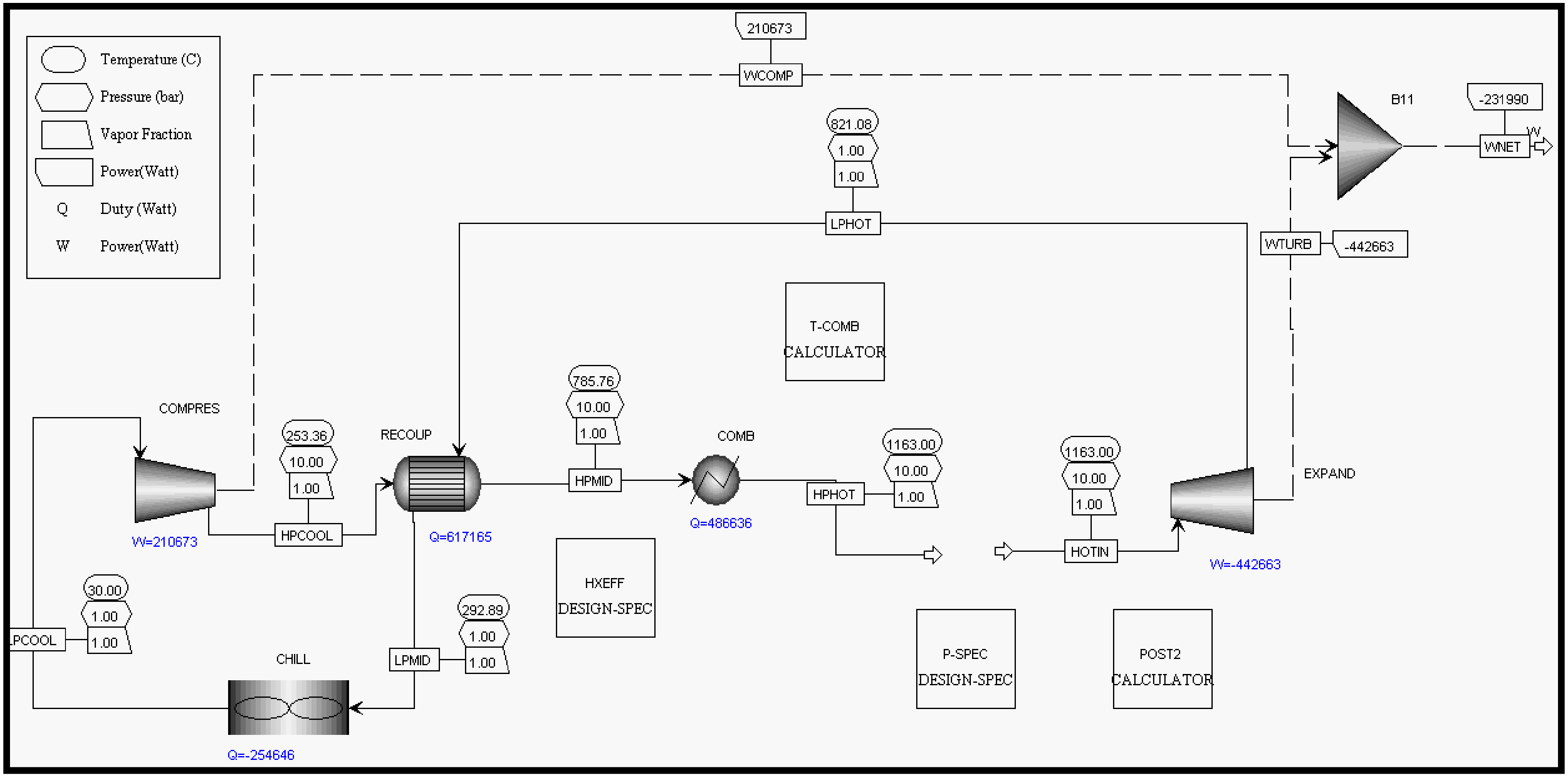
Outline

- Technical Overview
  - Recuperated CO_2 Oxy-Fuel Cycle
  - Primary Surface Recuperator Technology
- Proposed Scope
  - Objective
  - Tasks
- Project Management
- Next Steps

Recuperated CO_2 Oxy-Fuel Cycle

- Cycle analysis setup
- Validation with existing Mercury 50 recuperated air Brayton cycle
- Analysis of recuperated CO2 Oxy-fuel cycle
- Analysis results
- Heat Exchanger design conditions

Recuperated CO_2 Oxy-Fuel Cycle



T_{hot} [°C]	1163*	P_{high} [bar]	10
T_{cold} [°C]	30	P_{low} [bar]	1

*Same as Solar Turbines' Mercury 50 Gas Turbine

Recuperated CO_2 Oxy-Fuel Cycle

Modeling Parameters	
Compressor Isentropic Efficiency	80.0%
Turbine Isentropic Efficiency	83.3%
Heat Exchanger Effectiveness	93.0%
Cycle Analysis Results	
Cycle	Efficiency
Recuperated Air Brayton Cycle	40.0%
Oxy-Fuel Recuperated CO_2 Brayton Cycle	47.7%

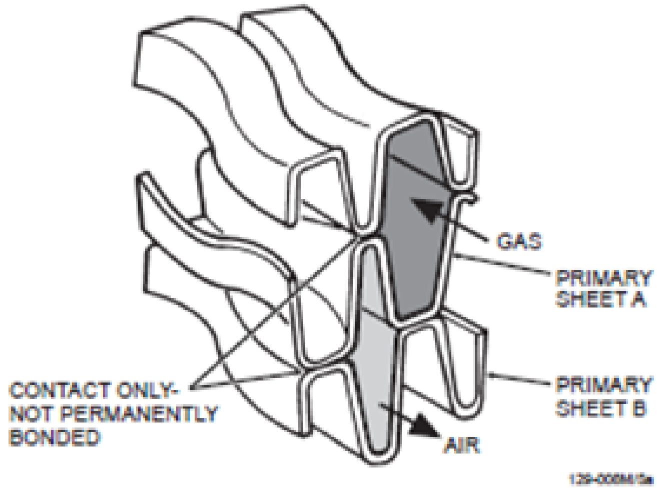
Cycle efficiency is expected to over 50% when combined with a bottoming ORC cycle.

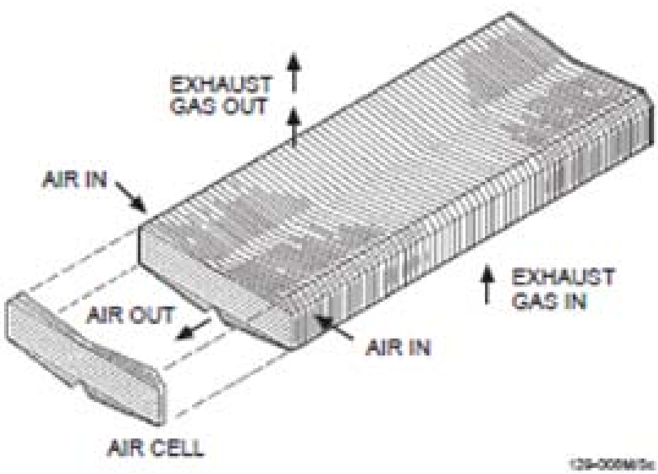
Recuperated CO_2 Oxy-Fuel Cycle

- Cycle advantages
  - Over **50% thermodynamic efficiency** when paired with a bottoming ORC cycle
  - Oxy-fuel cycle provides **sequestration-ready CO2** stream (needs compression)
  - 70% volume flow compared with air cycle at equivalent power => **reduced size of turbomachinery and heat exchangers**

Primary Surface Heat Exchanger Technology

- Developed in early 1970s for vehicle engine recuperators
- Established technology is widely used in Mercury 50 gas turbine and multiple microturbines
- Core composed of cells constructed from 2-8 mil Inconel 625 corrugated sheets
- Clamped design allows assembly to flex, reducing thermal stresses
- Sheet contacts provide damping.

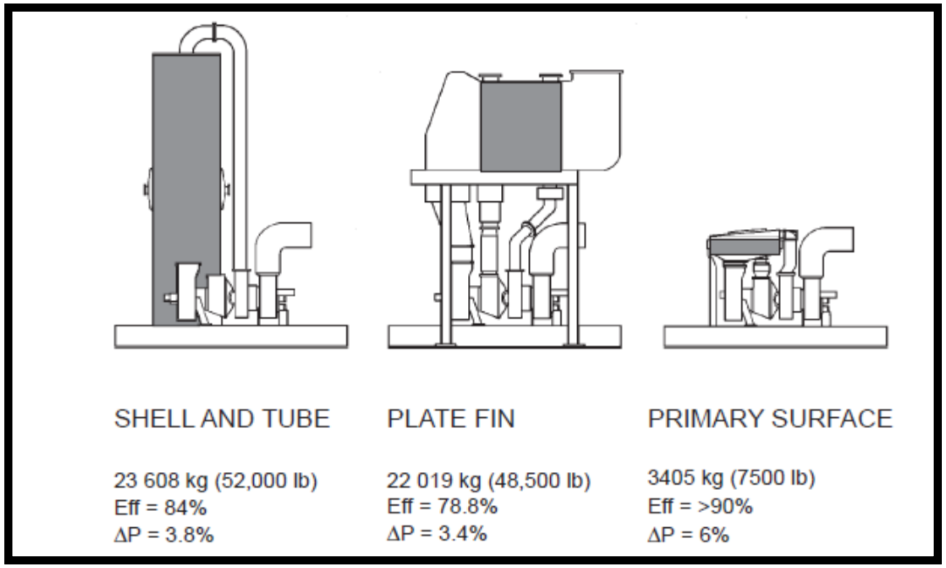




PSR Core Assembly

Primary Surface Heat Exchanger Technology

- High effectiveness (92-93%)
- Compact size
- Limited to low-DP cycles (currently 9 bar)
- Current design operates up to 1200°F (650°C)



Recuperator Development Needs

- Several technical challenges must be overcome for proposed cycle:
  - Material with sufficient tensile and creep strength at 1510°F (821°C)
  - Oxidation-resistant material/coating in high-temperature CO_2
  - Oxidation data unavailable above 600-700°C.
  - Mechanical stresses must be minimized by design to avoid creep and low-cycle fatigue failures
  - Maintain cost-effectiveness

Project Objective

- Develop a high-temperature heat exchanger design concept for operation in CO_2 at 1510°F (821°C) and differential pressure up to 130 psi (9 bar).
- Proposed for use in low pressure oxy-fuel Brayton cycle, but may also be used in other high temperature, low differential pressure cycles.

Project SOPO Tasks

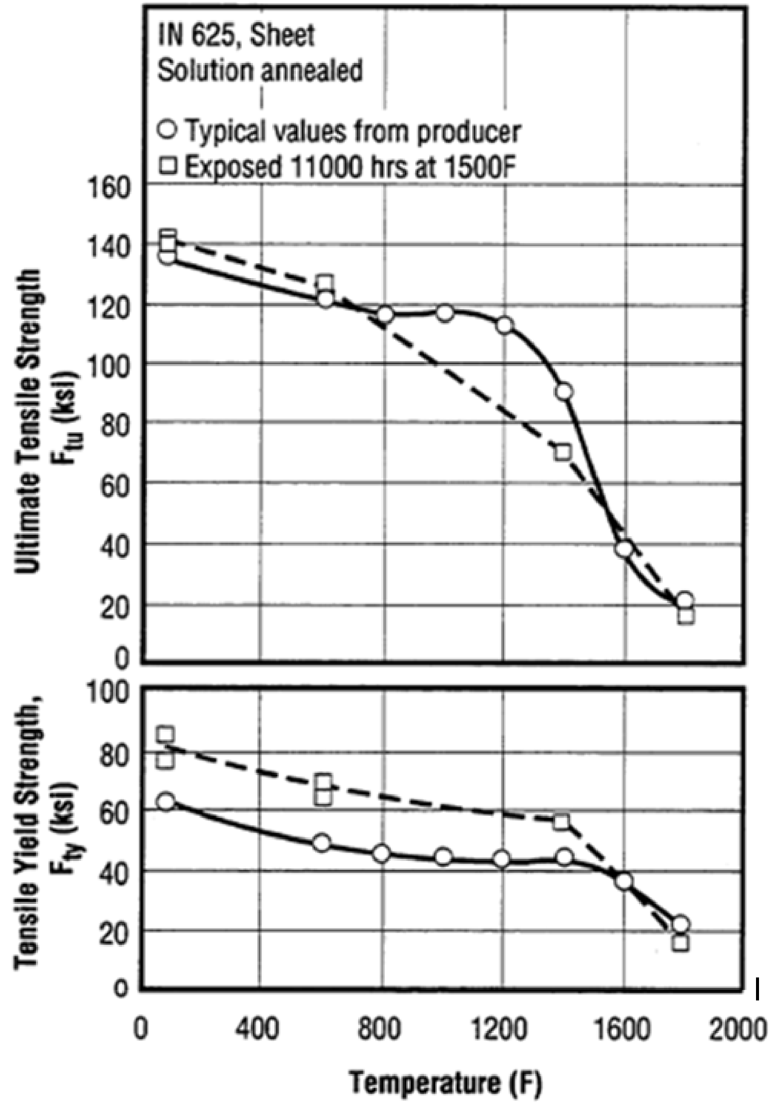
- Task 1 – Project Management & Reporting
- Task 2 – System Analysis
- Task 3 – Materials and Coatings Evaluation
- Task 4 – Recuperator Mechanical Redesign
- Task 5 – Test Loop Preliminary Design

Task 2 – System Analysis

- Subtask 2.1: Thermodynamic Analysis
  - Predict system performance of recuperator design using calculated heat exchanger effectiveness
  - Predict fuel consumption
- Subtask 2.2: Economic Analysis
  - Predict capital and operating cost based upon material selection and thermodynamic analysis (fuel consumption)
  - Identify cycles where cost effective to include the recuperator
- Results will be updated for each recuperator redesign option/iteration, to allow the comparison

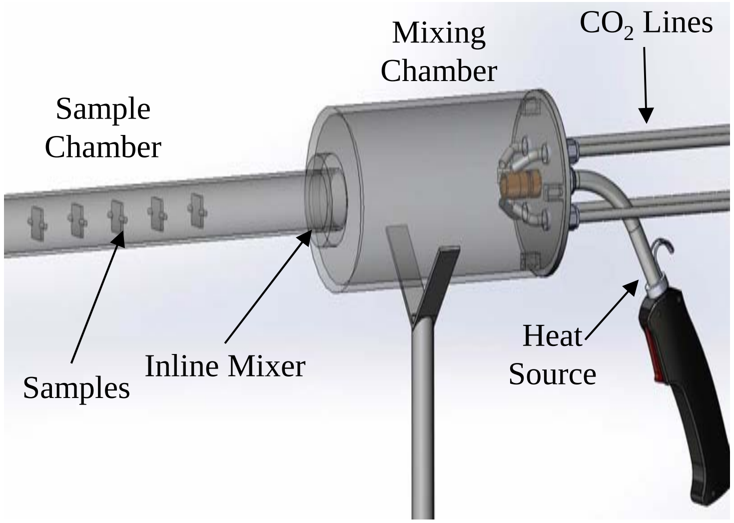
Task 3 – Materials and Coatings

- Subtask 3.1: Review and rank high-temperature materials and coatings by comparing formability, weldability, oxidation resistance, creep strength, and cost
  - Nickel-base alloys (Inconel 625/718, Haynes 282, etc.)
  - Alumina- or chromia-forming stainless steels
  - Nanocoatings or ceramic coatings



Task 3 – Materials and Coatings

- Subtasks 3.2 & 3.3: High temp bench-scale CO2 corrosion test rig design and operation
- Option 1: Custom built test rig
  - Allow tuning to more closely match existing conditions
  - Flexibility in testing conditions, times, etc.
  - Custom or existing coupons for testing
  - Design and build required for test rig and samples

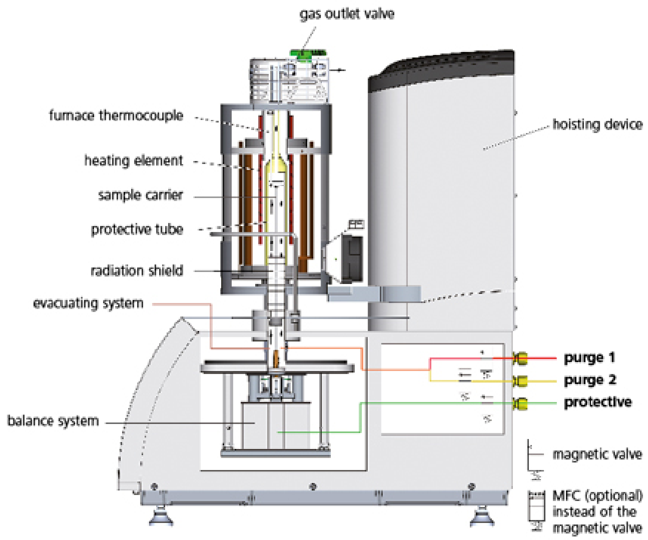


Task 3 – Materials and Coatings

- Option 2: Tube furnace
  - Existing equipment that is already operational
  - Basic furnace with CO_2 environment capability
  - Can provide a high quality CO_2 gas
  - Limited on gas flow rates

Task 3 – Materials and Coatings

- Option 3: Simultaneous Thermogravimetry Differential Scanning Calorimetry (STDSC)
  - Precise in measuring capabilities
  - Smaller sample sizes required
  - Limited on gas flow rates, reduced precision at higher flows



Task 4 – Recuperator Redesign

- Subtask 4.1 Develop and Validate Mechanical Model for Existing Recuperator
  - Solar to provide design information and model of recuperator core
  - SwRI to add ducting as necessary to simulate stresses
  - Simulate recuperator at air cycle conditions and verify HX effectiveness and thermal stresses with Solar values

Task 4 – Recuperator Redesign

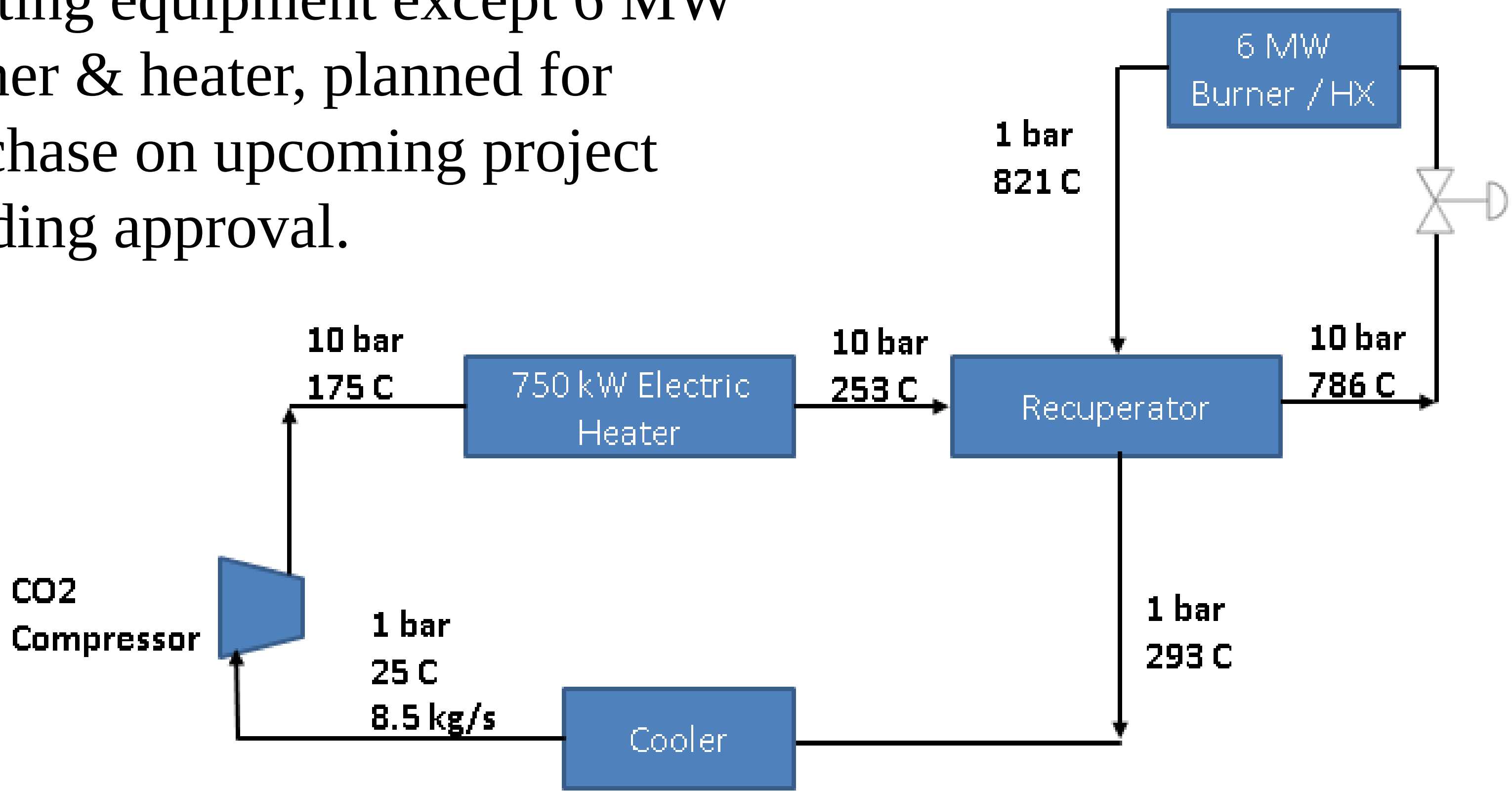
- Subtask 4.2 Concept Study of Redesign Options
  - New material, changing cell size, primary surface thickness, rearrangement of clamping bars and/or weld geometry, additional stress reduction features at high-stress areas
  - Develop matrix to evaluate advantages and disadvantages, including estimated costs.
- Subtask 4.3 Mechanical Design and Analysis of Selected Concepts
  - Finite Element Analysis, Conjugate Heat Transfer Analysis
- Subtask 4.4 Design drawings and Quotes

Task 5 – Test Loop Preliminary Design

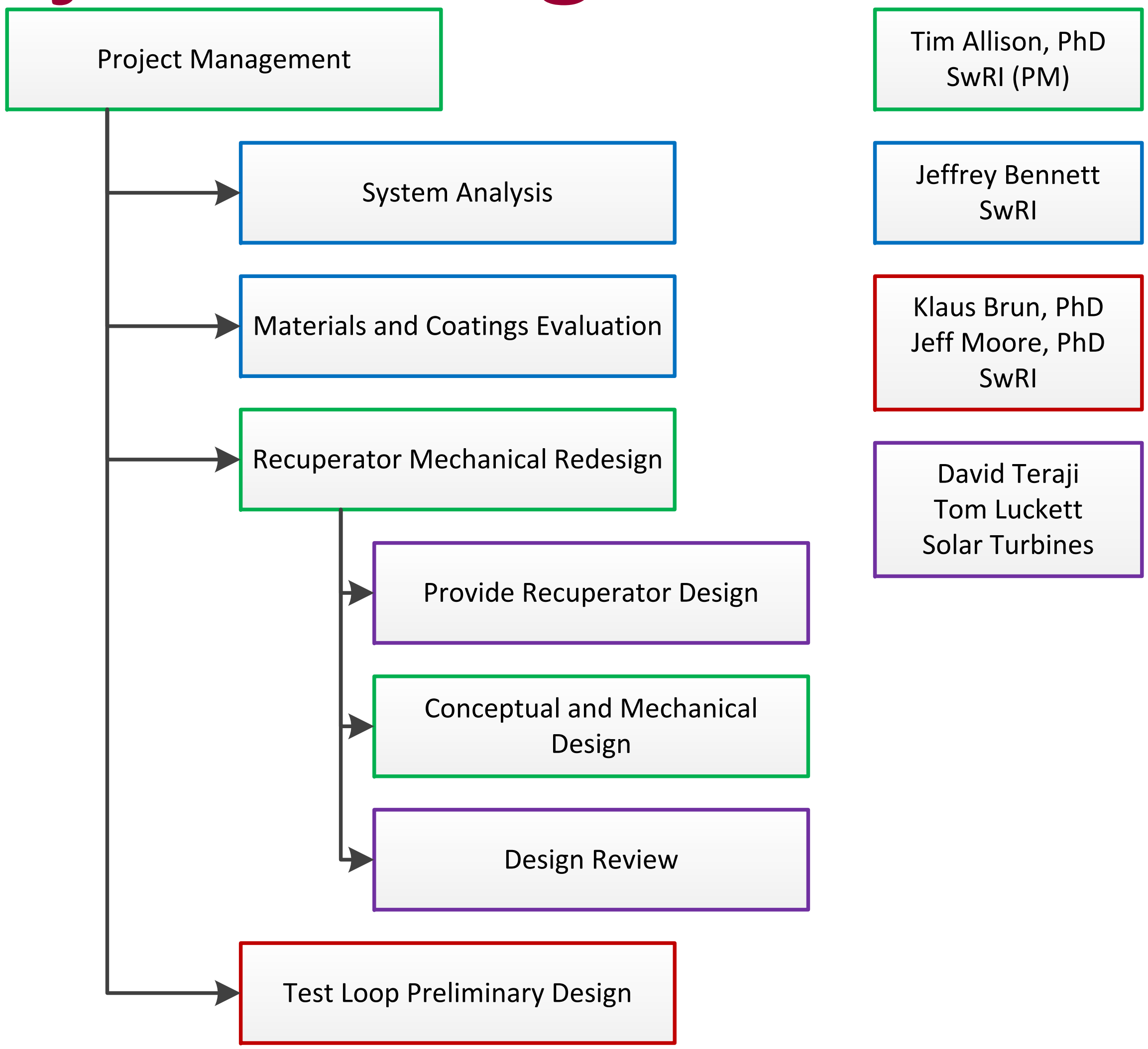
- Design layout and components for test loop for future full-scale testing of recuperator
  - No testing in current scope
  - Design necessary for costing information for future work
- Minimize cost by utilizing existing CO2 compression facility at SwRI. Potentially use existing heaters, coolers, etc.

Task 5 – Test Loop Preliminary Design – 70%% Flow Concept

All major components are existing equipment except 6 MW burner & heater, planned for purchase on upcoming project pending approval.

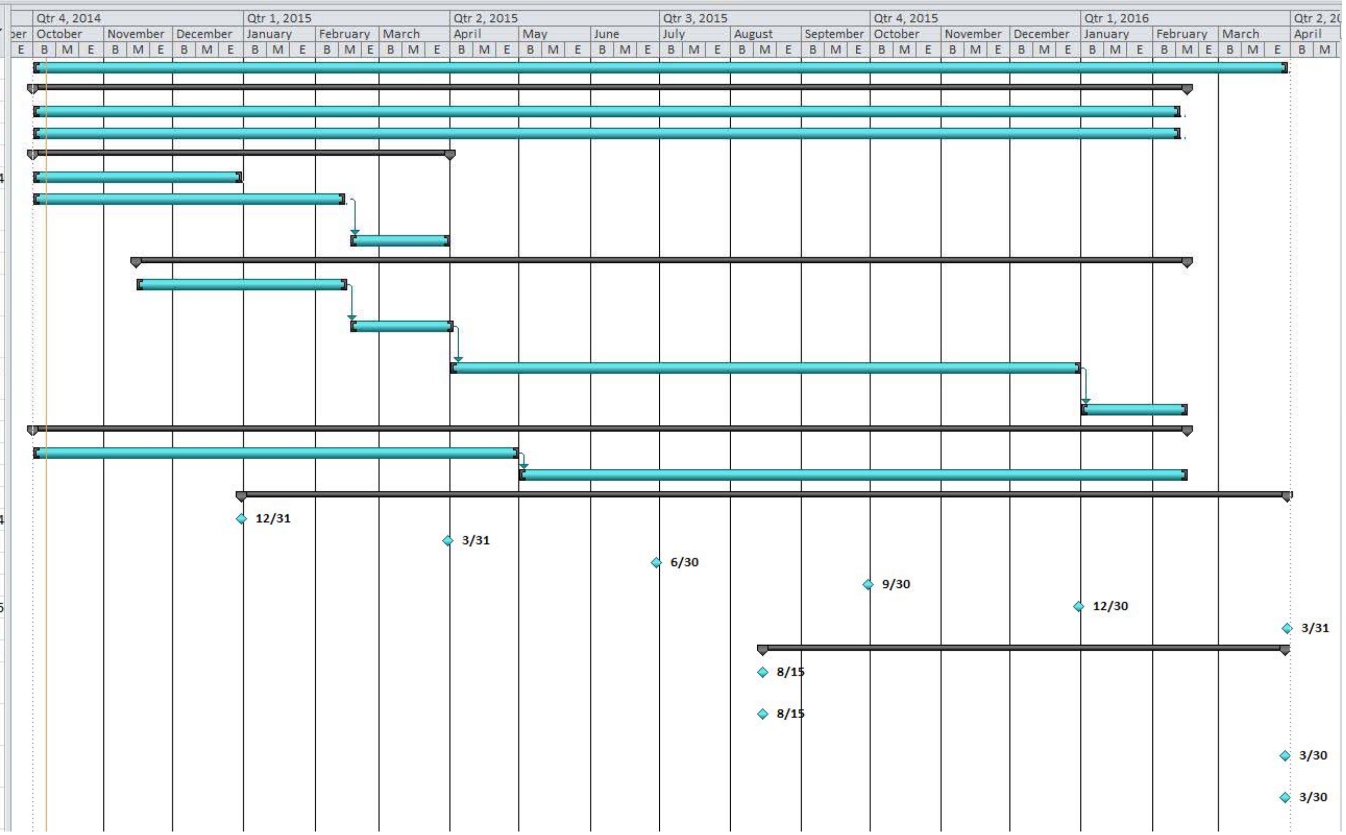


Project Management - Roles



Project Management – 18 Month Timeline

Task Name	Start	Finish
1 - Project Management	Wed 10/1/14	Thu 3/31/16
2 - System Analysis	Wed 10/1/14	Mon 2/15/16
Task 2.1 - Thermodynamic Analysis	Wed 10/1/14	Mon 2/15/16
Task 2.2 - Economic Analysis	Wed 10/1/14	Mon 2/15/16
3 - Materials and Coatings Evaluation	**Wed 10/1/14**	**Tue 3/31/15**
Task 3.1 - Review of Materials and Coatings	Wed 10/1/14	Wed 12/31/14
Task 3.2 - Laboratory-Scale Coupon Test Rig Design and Fabrication	Wed 10/1/14	Sun 2/15/15
Task 3.3 - Laboratory-Scale Coupon Testing	Mon 2/16/15	Tue 3/31/15
4 - Recuperator Mechanical Redesign	**Sat 11/15/14**	**Mon 2/15/16**
Task 4.1 - Development and Validation of Mechanical Model for Existing Recuperator	**Sat 11/15/14**	Sat 2/14/15
Task 4.2 - Concept Study of Redesign Options for Higher Temperatures	Mon 2/16/15	Wed 4/1/15
Task 4.3 - Mechanical Design and Analysis of Selected Concepts	Wed 4/1/15	Thu 12/31/15
Task 4.4 - Design Drawings and Quotes	Fri 1/1/16	Mon 2/15/16
5 - Test Loop Preliminary Design	**Wed 10/1/14**	**Mon 2/15/16**
Task 5.1 - Conceptual Design	Wed 10/1/14	Thu 4/30/15
Task 5.2 - Preliminary Design	Fri 5/1/15	Mon 2/15/16
6 - Reporting	**Wed 12/31/14**	**Thu 3/31/16**
Quarterly Report 1	Wed 12/31/14	Wed 12/31/14
Quarterly Report 2	Tue 3/31/15	Tue 3/31/15
Quarterly Report 3	Tue 6/30/15	Tue 6/30/15
Quarterly Report 4	Wed 9/30/15	Wed 9/30/15
Quarterly Report 5	Wed 12/30/15	Wed 12/30/15
Final Report	Thu 3/31/16	Thu 3/31/16
Milestones	**Sat 8/15/15**	**Wed 3/30/16**
Milestone 1 - Completion of concept study and selection of concepts for further detailed analysis	Sat 8/15/15	Sat 8/15/15
Milestone 2 - Completion of bench-scale coupon testing	Sat 8/15/15	Sat 8/15/15
Milestone 3 - Completion of preliminary design of high temperature heat exchanger	Wed 3/30/16	Wed 3/30/16
Milestone 4 - Completion of preliminary design for recuperator full-scale test loop	Wed 3/30/16	Wed 3/30/16



Project Management – Spend Rate