HIGH-EFFICIENCY LOW-COST SOLAR RECEIVER FOR USE IN A SUPERCRITICAL CO_2 RECOMPRESSION CYCLE

BraytonEnergy

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Project Start Date: 01 September 2012

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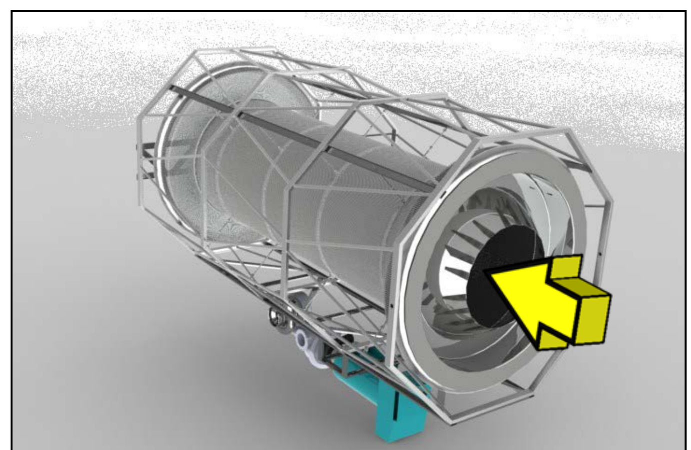


PROJECT OVERVIEW

DESCRIPTION: This project aims to develop and build a prototype high-efficiency, low-cost, highly-compact solar receiver that will enable the adaptation of a supercritical carbon dioxide (sCO_2) recompression cycle to a CSP heat source.

OBJECTIVES AND GOALS:.

PERFORMANCE METRIC	ENTRANCE BASELINE (non-$S\text{-}CO_2$ state-of-the-art)	PROJECT TARGET	EXIT DELIVERABLE (Deliverable Phase)	CONTRIBUTION TO LCOE REDUCTION
Receiver Creep Life	30,000 hours	40,000 hours	Receiver Creep-Life Analysis Report (1)	Extended Solar Plant Life
Receiver Fatigue Life	10,000 thermal cycles w/o failure	≥ 10,000 thermal cycles w/o failure	Receiver Fatigue-Life Analysis Report (1)	Extended Solar Plant Life
Receiver Cost	$\$150\text{-}200/kW_{th}$	$\$30/kW_{th}$	Production-level BOM cost roll-up incl. fab. (prelim 1/final 2)	Reduction in cost, mass of receiver, supporting structures
Receiver Pressure Drop	5% DP/P	< 5% DP/P	Extended surface tube flux test report (2)	Contributes to high efficiency engine cycle, reduction in field or dish size
HTF Exit Temperature	400-600°C	750°C	On-sun receiver test report (3)	Enables use of highly efficient (≥50%) $S\text{-}CO_2$ cycle for solar application
Average Annual Thermal $\eta_{receiver}$	80-95%	> 92%	On-sun receiver test report (3)	Contributes to high efficiency engine cycle, reduction in field or dish size

PROGRAM APPROACH

- Numerical Modeling
  - Fast and flexible finite difference HT and flow models
  - Supported by concurrent CFD studies
- Manufacturing Trials
  - Developing and demonstrating new methods
- Component Testing
  - Demonstrating creep life, fatigue life, and oxidation resistance of critical components in laboratory test rigs
- Prototype Demonstration
  - On-sun evaluation of a solar receiver test loop

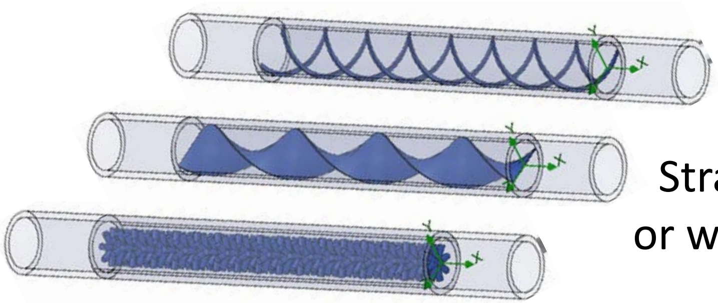
LAYOUT DEVELOPMENT

- Internal (cavity-type) vs. External Receiver

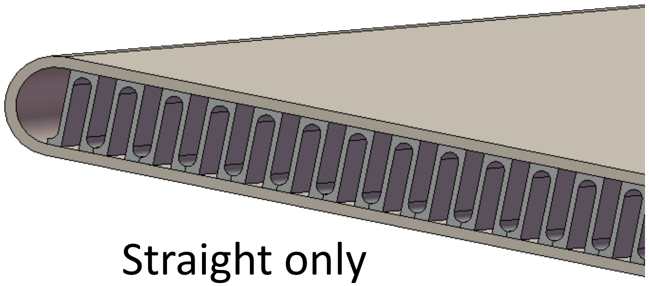
South-facing field
~5 MW_{th} maximum
Higher efficiency

Full-Surround Field
100+ MW_{th} max.
Lower efficiency

- Tube or Plate/Panel Construction

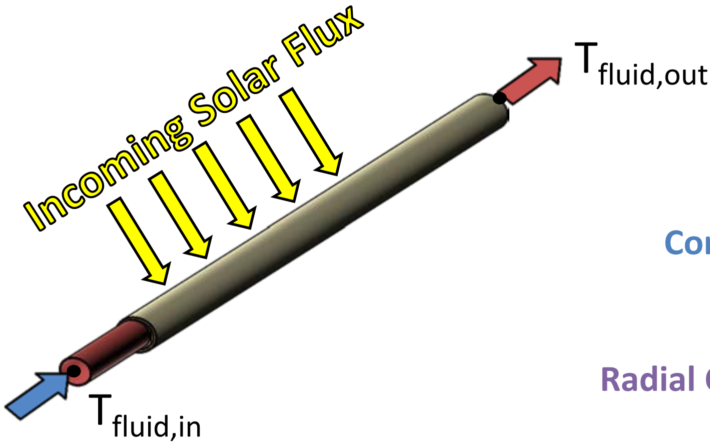


Straight
or wound

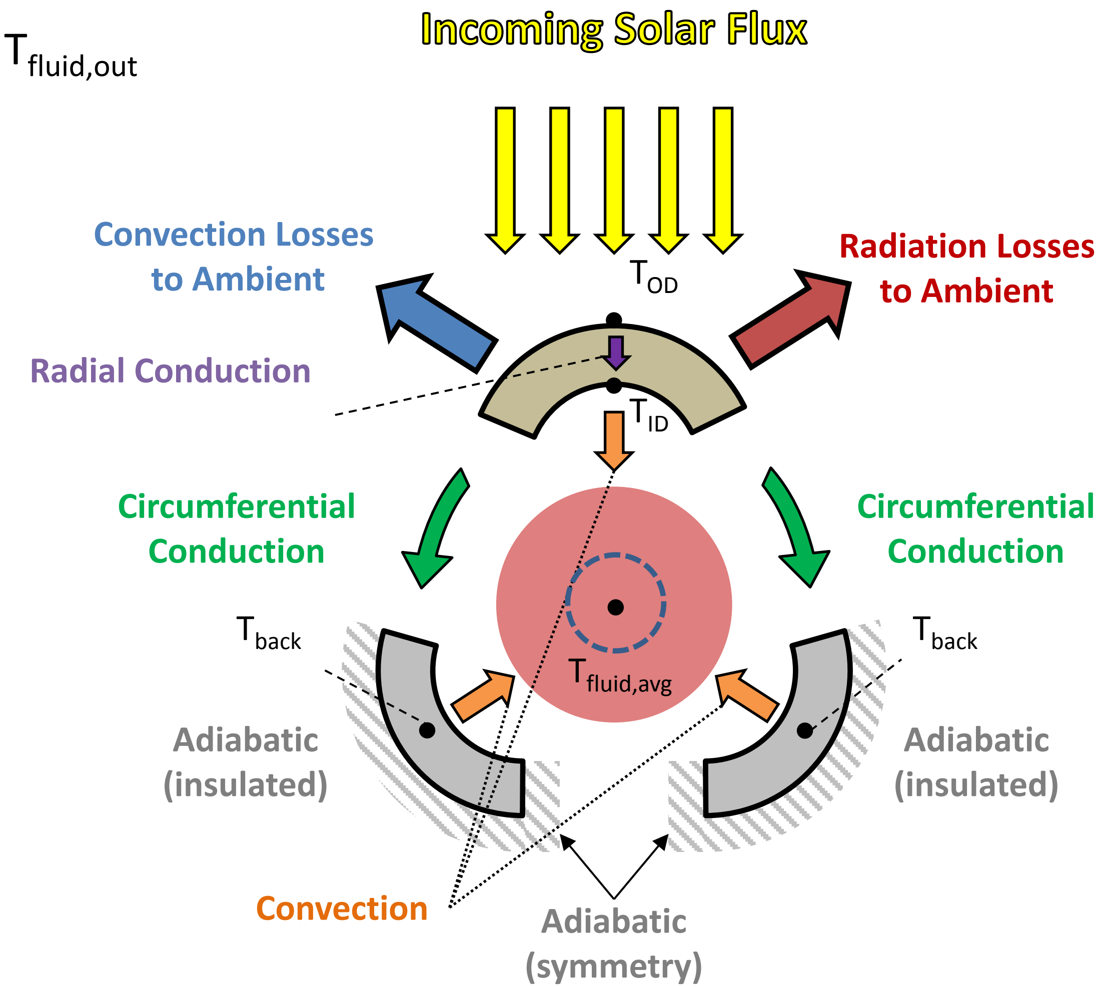


Straight only

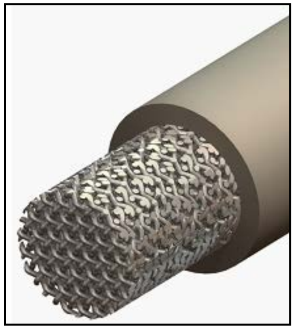
Plain/Center-body Tube F-D Analysis

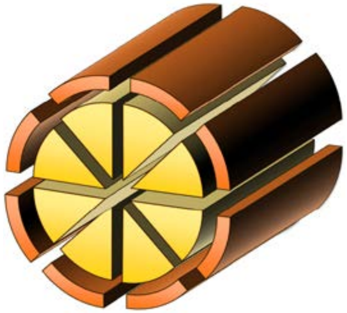


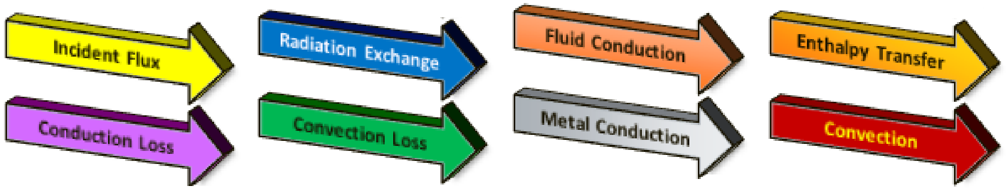
- $T_{wall,max}$
- $T_{fluid,out}$
- $\Delta T_{circum,\ max}$
- $\Delta T_{radial,max}$
- ΔP_{fluid}

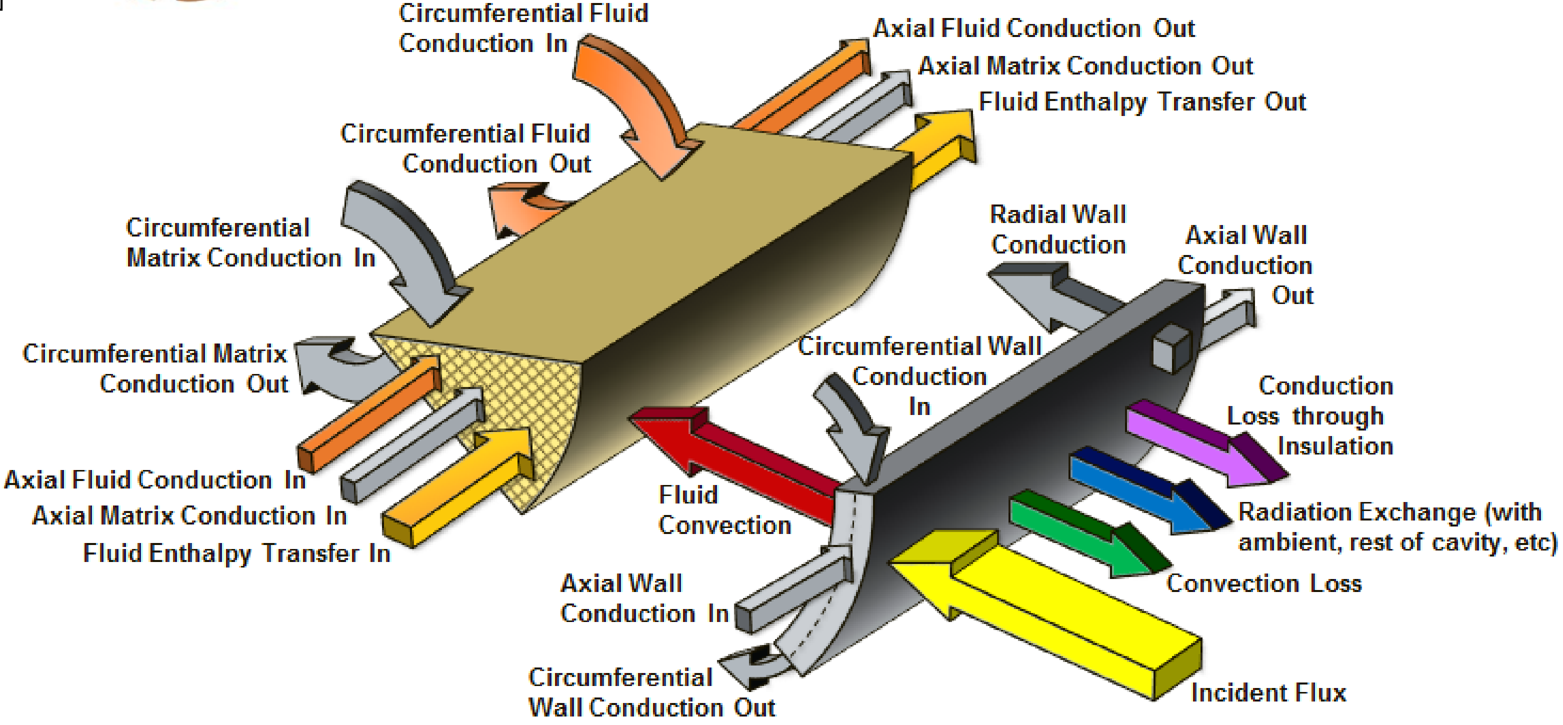


EXTENDED-SURFACE TUBE F-D ANALYSIS

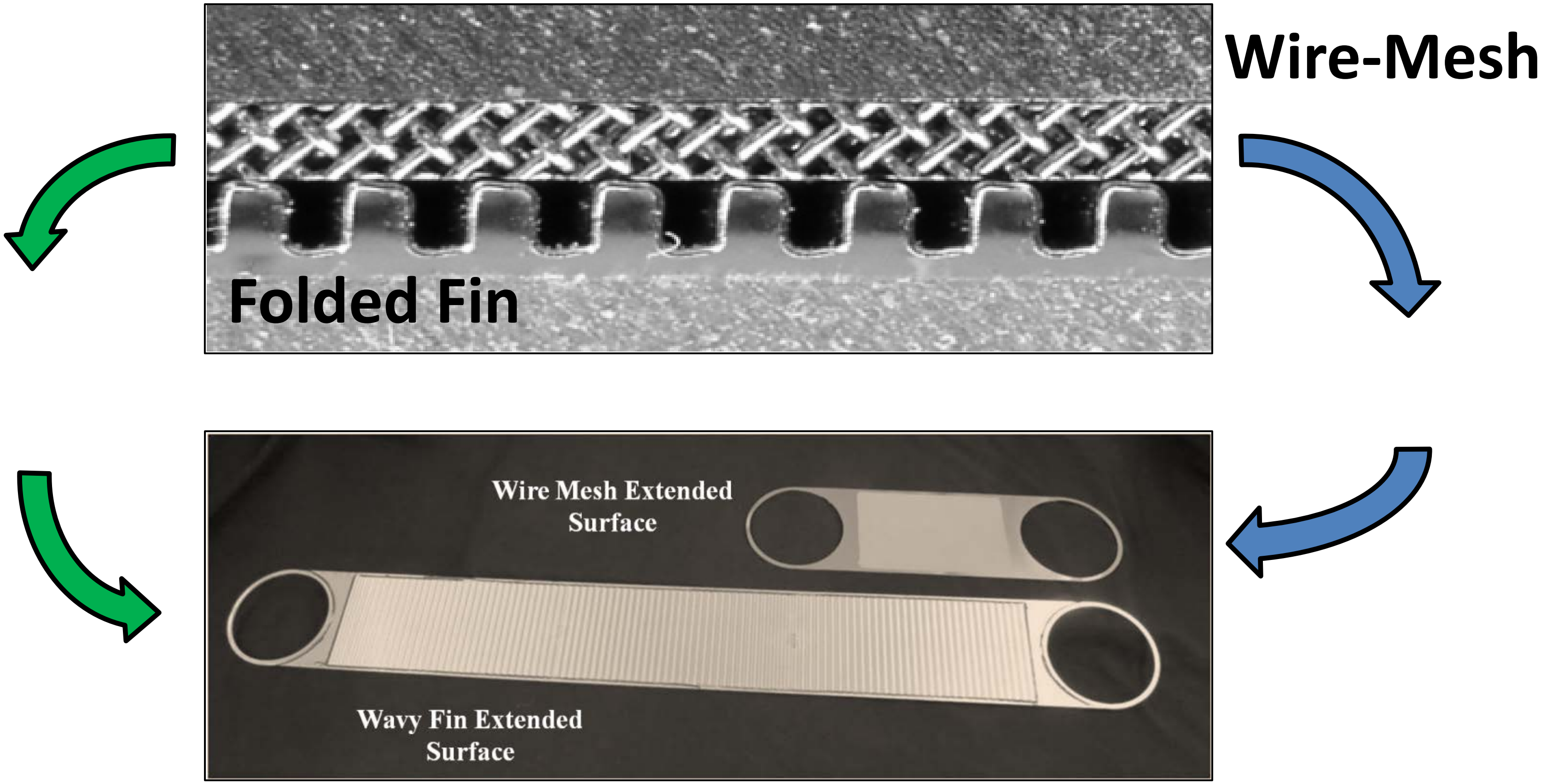








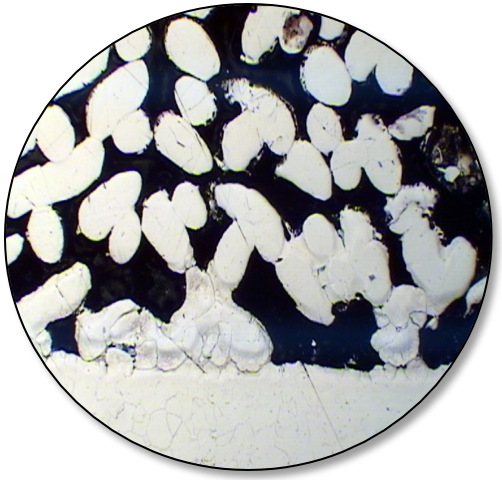
Extended Heat Transfer Surfaces



WIRE-MESH BONDING

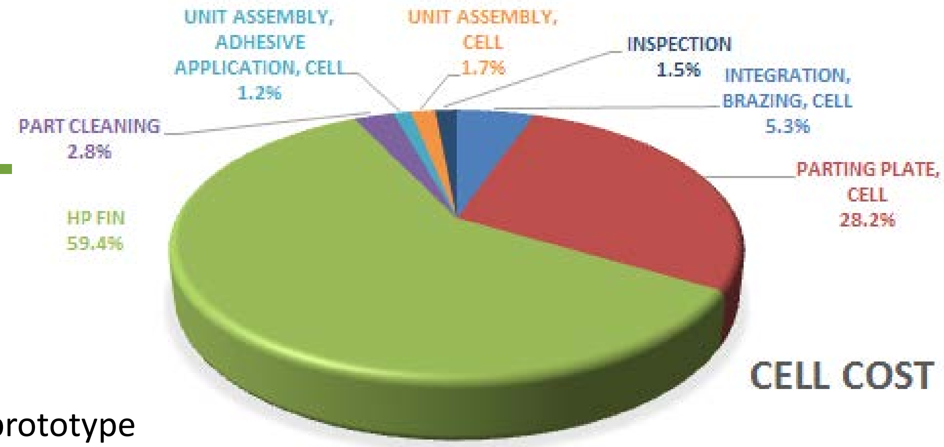
- The geometry of the wire matrix is controlled and oriented to optimize strength and thermal performance
- The surface topology of the cut mesh is critical to effective metallurgical bonding; cutting methods and post-cut treatments were thoroughly explored

Wire mesh matrix with US dime shown for scale



Cutaway micrograph showing wire strands and inter-wire flow-space

Cost Modeling



Overall Assumptions

- Design definition is sufficient to provide quantity, material type, volume (cm^3) and a basis for developing a manufacturing strategy per component
- All units are factory 'production'; i.e. 1st unit is not a prototype
- No non-recurring costs (engineering, prototype testing, permitting, etc.)

Raw Material Costs

- Raw material costs based on purchase order database and/or vendor quotes
- Material costs used in this model are sourced from prevailing data

Labor Costs

- Labor costs are calculated by developing a manufacturing flow process per component and assigning times and labor type to each step in the process
- Manufacturing process based on experience with similar components
- Hourly Labor Costs
- Wage rates as per Bureau of Labor Statistics National Labor Rates - NAICS 333600 - Engine, Turbine, and Power Transmission Equipment Manufacturing

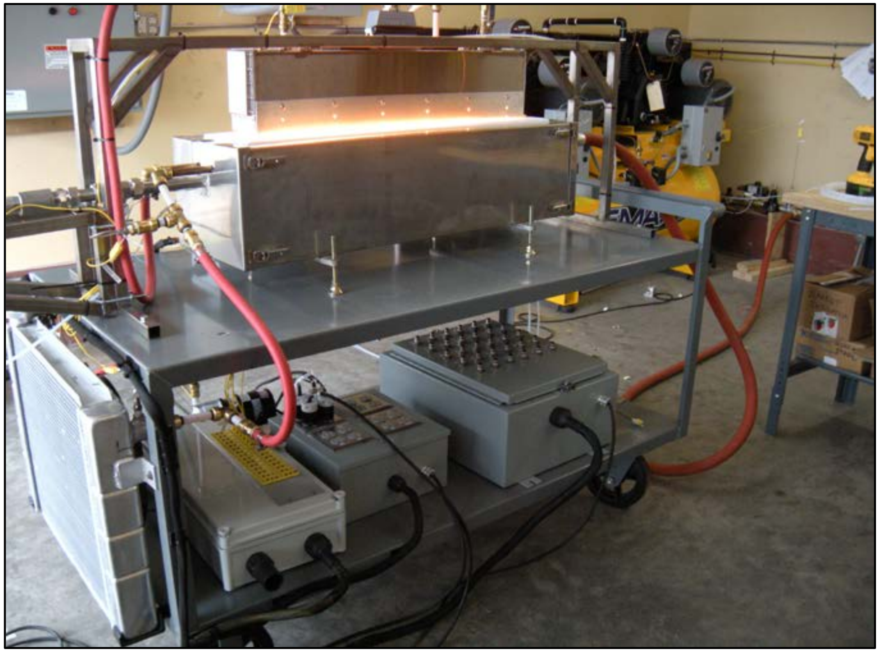
Learning Curve

- Learning curve is a log function based on the T.P. Wright learning curve. Each time the quantity produced is doubled, the projected cost equals the original cost multiplied by the learning curve percentage.
- Learning curve is assumed continuous. Each type of manufacturing technology has a unique learning curve
- The learning curve value is assigned based on a combination of NASA's cost estimation and costing consultants referenced for previous cost models

EFFORTS TO DATE: COMPONENT TESTING

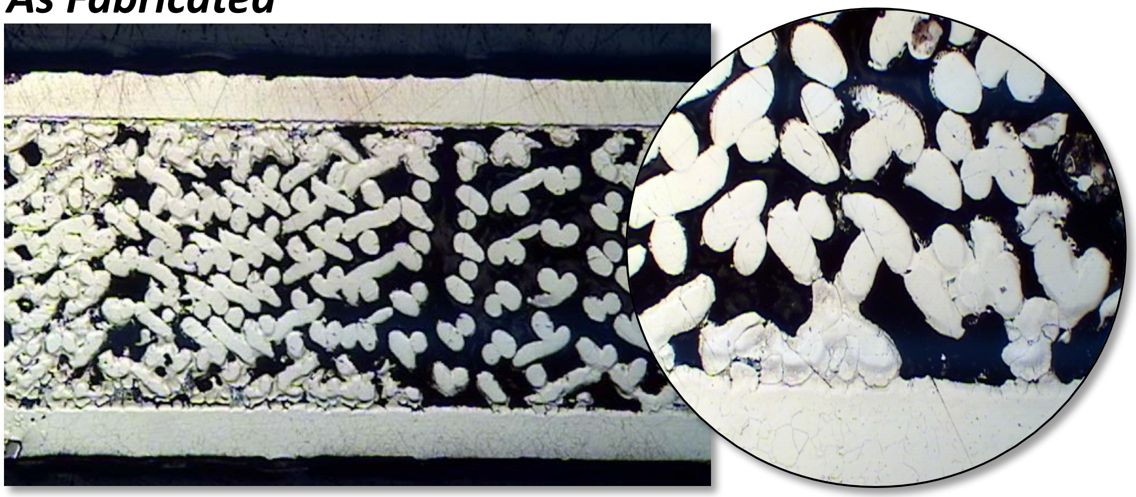
- High-Temp. Furnace
  - Oxidation Resistance
  - Creep Life

- High Flux Test Rig
  - Fatigue Life
    - Thermo-Mechanical Deflections



HYDROSTATIC BURST TESTING

As Fabricated



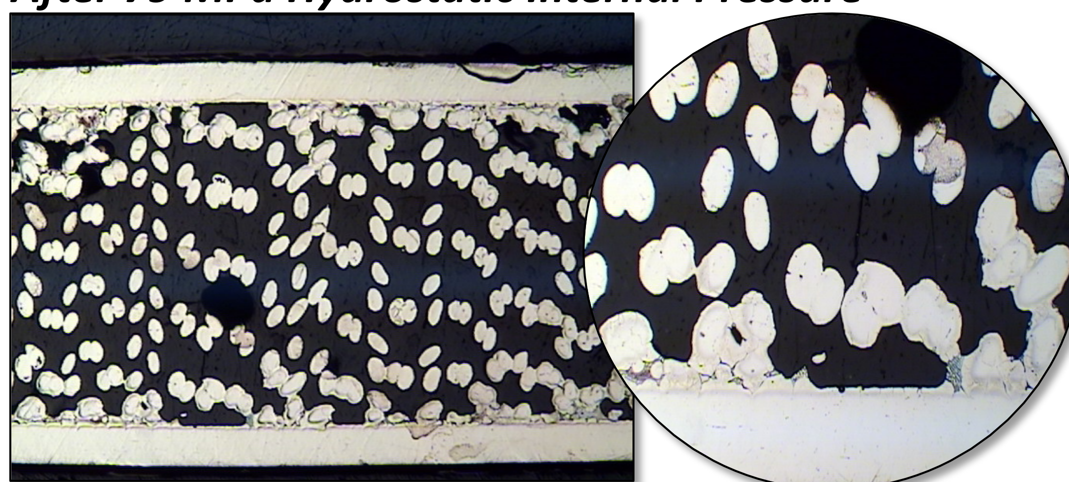
- Observed failures have been in the parent material, not in the metallurgical bond or mesh matrix

Initial Hydrostatic Test Results

P, MPa	Notes
78.6	Distortion, No Burst
79.3	Distortion, No Burst
82.7	Distortion, No Burst
60.7	Failure

* Versus 50 MPa Requirement

After 79 MPa Hydrostatic Internal Pressure



RESULTS AND THEIR SIGNIFICANCE

- Development of finite-difference Models to analyze candidate receiver architectures
  - Both external and internal cavity-type layouts
  - Identified IN-625 layouts that meet life and H.T. req's.
    - ***Receiver performance goals, though ambitious, are attainable***
- Agreements & NDAs signed with sCO_2 CSP engine developers
  - discussions on state-points, requirements, solar fluxes, etc.
    - ***The better the communication between interested parties, the more directly applicable the design may be to a real CSP installation***
- Bonding of wire-mesh matrices to substrate material
  - Development of low-cost manufacturing methods
  - Demonstrated burst pressures > 50 MPa requirement
    - ***Architectures are capable of performing at the required high pressures and elevated temperatures***
- Developed cost models to analyze candidate designs
    - ***Preliminary Indications suggest that the aggressive cost targets are indeed reasonable***

The technologies under development are capable of meeting the program objectives

CHALLENGES (AND MITIGATIONS)

- It is challenging to identify a solar field configuration (and hence solar flux profile) that is relevant to the sCO_2 CSP engine systems currently under development.
  – Representative fluxes can be initially applied with suitable margins provided on performance and temperatures

- Implementation of wire mesh matrices has required engineering and manufacturing development to refine the process and achieve the desired results.
  – Wire matrix, wavy fin, and center-body tube configurations have been identified which meet the heat transfer and pressure-drop requirements
  – Brayton Energy's experience with unit-cell plate-fin gas turbine recuperators (rated to 10,000 psi, suitable for sCO_2 applications) is being leverage.

Future Work

- Install components in test rigs for testing
- Finish preliminary system modeling for candidate designs; down-select design for prototyping
- Produce annualized performance prediction for fully implemented design
- Develop, fabricate, and install solar test rig
- Fabricate and test prototype solar receiver on test rig