SunShot
U.S. Department of Energy

CSP Program Summit 2016

HIGH FLUX MICROCHANNEL SOLAR RECEIVER DEVELOPMENT

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PROJECT OVERVIEW

Oregon State University
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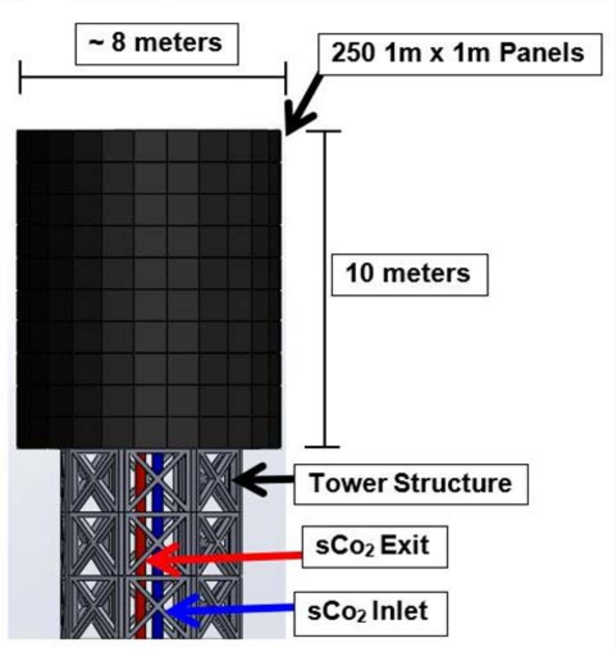
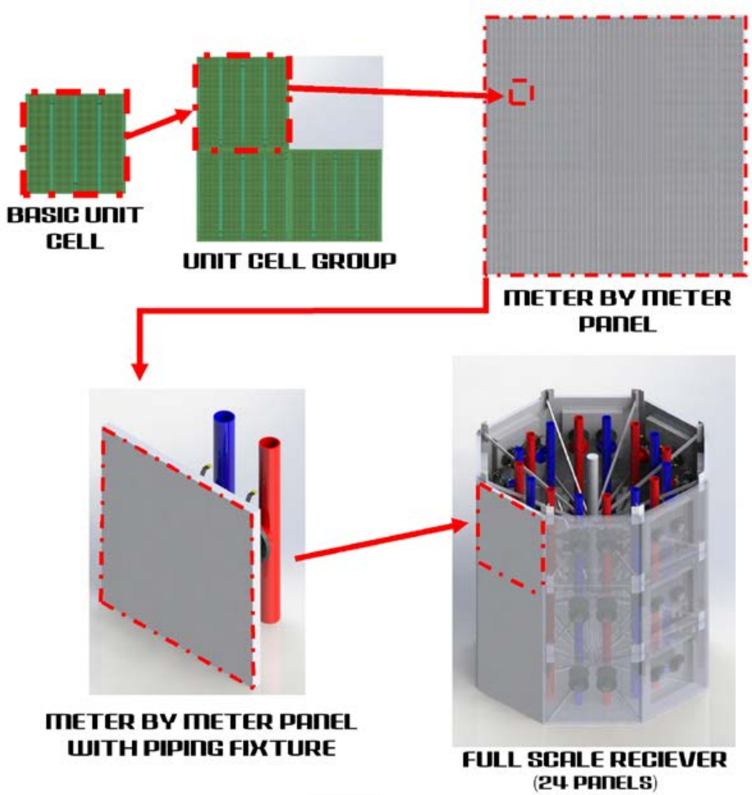
DOE Phase Funding: $2,000,000
Cost-Share Phase Funding: $580,638
Principal Investigator: Kevin Drost (OSU)
Project Team:

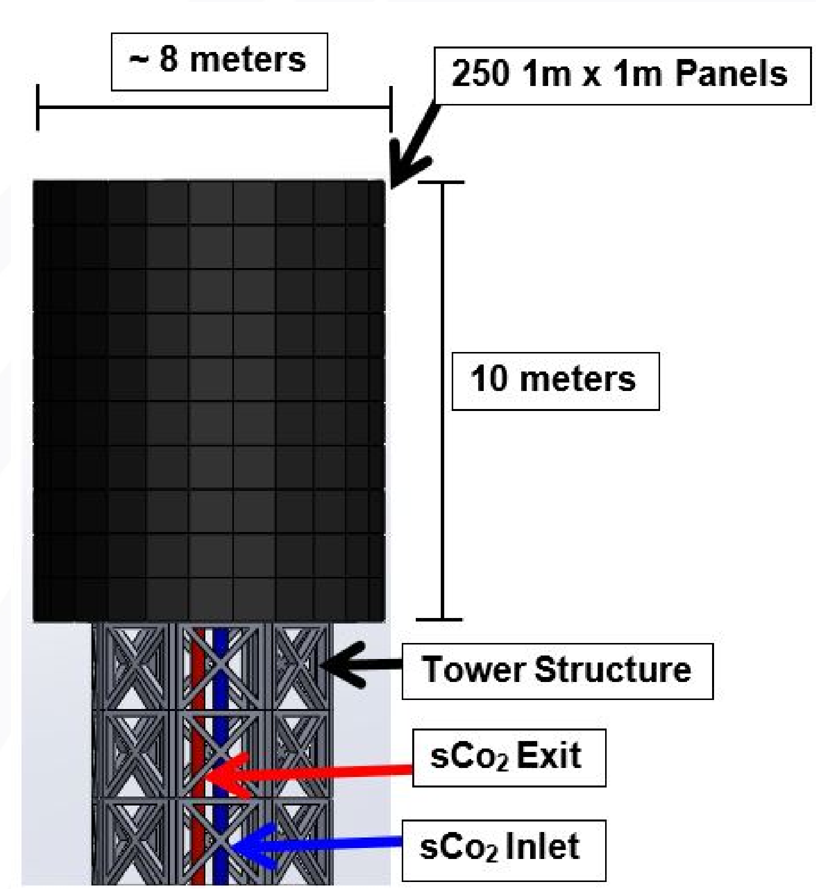
- Oregon State University (OSU)
- National Energy Technology Laboratory (NETL)
- Sandia National Laboratory (SNL)
- Pacific Northwest National Laboratory (PNNL)
- University of California, Davis (UCD)
- ECOKAP



Microchannel Solar Receiver Concept

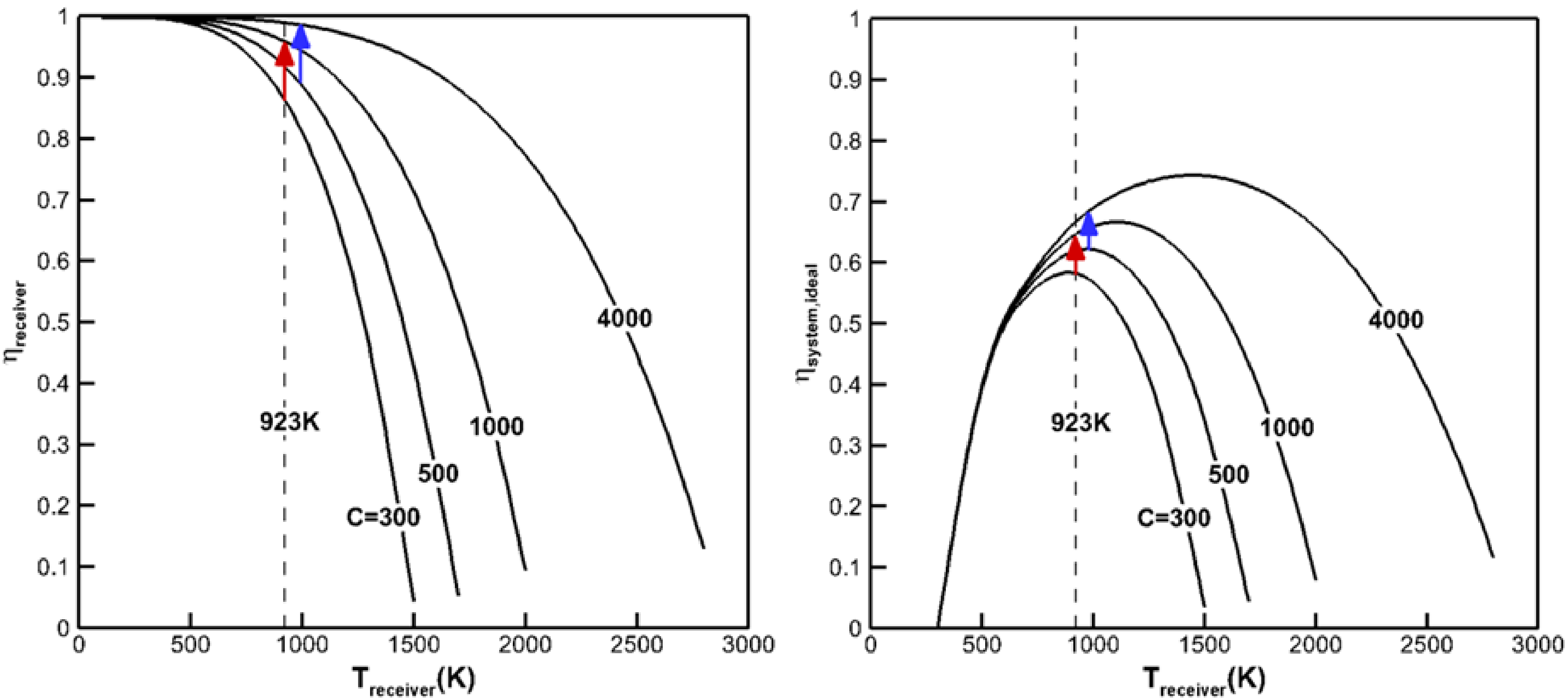
TECHNOLOGY OVERVIEW





- Multi-scale model
- Unit cell → Module (~1 m^2) → Full Receiver

Problem Statement: For high temperature operation we need to increase the incident flux on the receiver



At 650 °C, going from 30 W/cm² to 100 W/cm² increases receiver efficiency from 86% to 96 % and ideal system efficiency from 57% to 65%.

Value Propositions - Why High Flux?

- If we can attain a higher receiver flux at high thermal efficiency, we obtain the following benefits
  - Smaller and significantly less costly receiver
  - Less costly tower
  - Reduced thermal losses
    - Assuming a constant receiver external temperature distribution, thermal losses are a direct function of surface area
    - Impact permeates through the plant design reducing the size and cost of the field
    - Enables use of high temperature heat transfer fluids and consequently more efficient power cycles
  - Avoid the need for and cost of a cavity (with spillage losses) or a cover glass (with absorption and reflection losses)
  - “Number up” not “scale up”

Background: Innovations

- To attain high flux, we need:
  - A small temperature difference between the surface of the receiver and the heat transfer fluid or the surface temperature rises with more thermal losses and material issue

    Solution: **Use microchannels for heat transfer**
  - Much higher heat transfer fluid flow rate per unit area of receiver or pressure drop rises

    Solution: **Use a large number of short parallel channels with a branching distribution system**

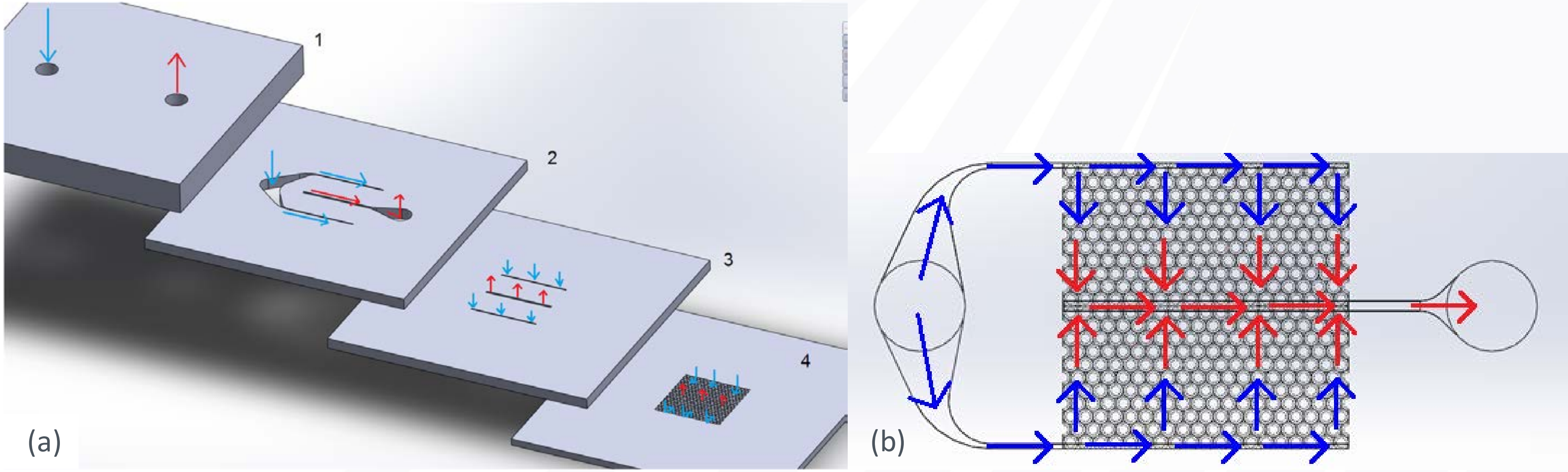
Project Objectives

- **Project Goals** - Develop the Microchannel Solar Receiver (MSR) from **TLR 3 to 5**, culminating in an on-sun test of a commercial scale receiver module with a surface area of approximately 1 square meter which:
  - Heats sCO2 from 550°C to 720°C with an incident flux of at least 100 W/cm2 and receiver efficiency of 90%;
  - Will have a lifetime of 12,000 cycles; and
  - Can meet the DOE receiver cost goals of $150/kWt.

Milestones

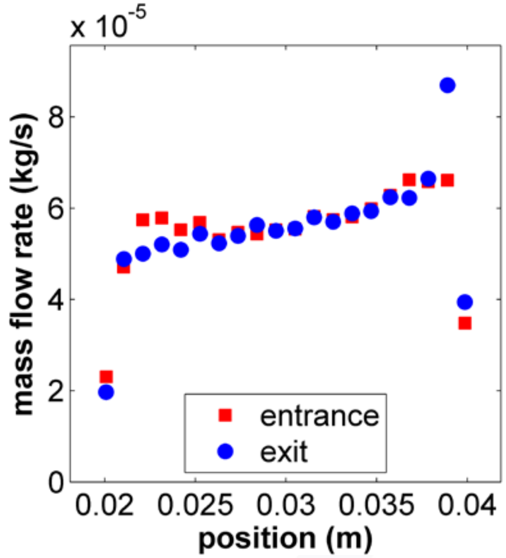
- **Phase 1 (10/15-10/16)**
  - Using laboratory testing to confirm that a viable fabrication process exists for the selected material and commercial module design (OSU and NETL).
  - Completing a design of a commercial-scale module that based on simulation can achieve a receiver efficiency of 90% (assuming the availability of a coating with 95% absorptivity) while heating sCO_2 from 550°C to 720°C with an overall receiver pressure drop less than 4 bars (OSU).
- **Phase 2 (10/16-10/17)**
  - Successful pressure testing of the subscale test article to 250 bars at 750 °C after pressure and temperature cycling and pressure testing commercial test article to 250 bars (OSU).
  - Test result from Parabolic dish testing consistent with a receiver efficiency of 90% (assuming the availability of a coating with 95% absorptivity) while heating sCO_2 from 550°C to 720°C with an overall receiver pressure drop less than 4 bars and temperature non-uniformity in an electrically-heated commercial module consistent with a flow distribution that varies less the 5% across the module (UCD).
  - Demonstrate, using analysis, that an installed 100 MW_e MSR will cost less than \$150/kW_t (PNNL).
- **Phase 3 (10/17-3/17)**
  - Complete on-sun test (OSU and SNL)
  - Complete commercialization plan (ECOKAP)

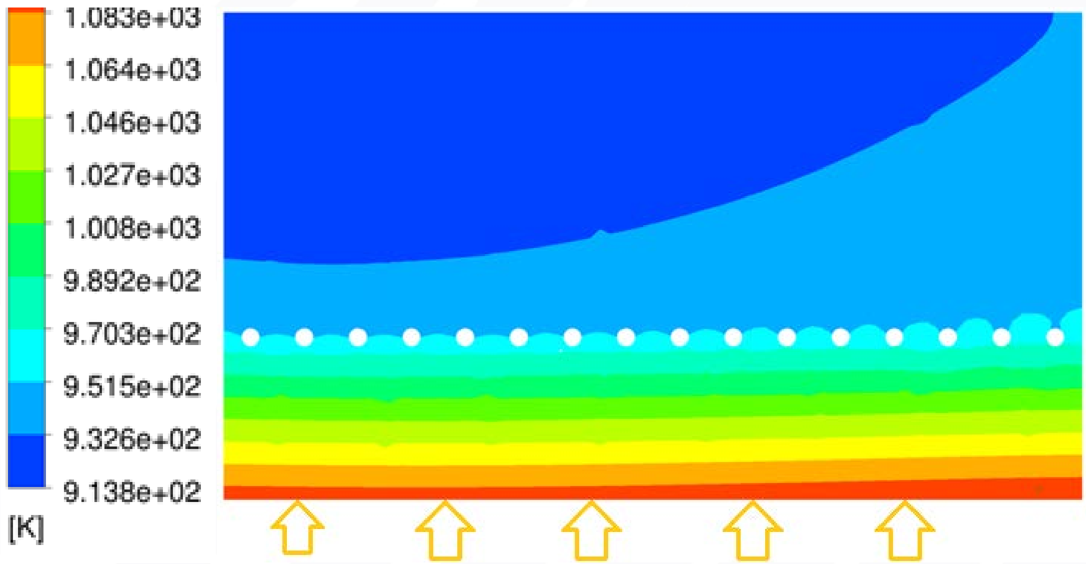
Results (Laboratory Investigations) - sCO_2 Test Article



Test article design: (a) exploded view and (b) wireframe top view . Blue arrows are inlet flow, red are outlet flow. Solar flux is incident on the bottom of plate 4.

Results - sCO_2 Test Article Simulation Results

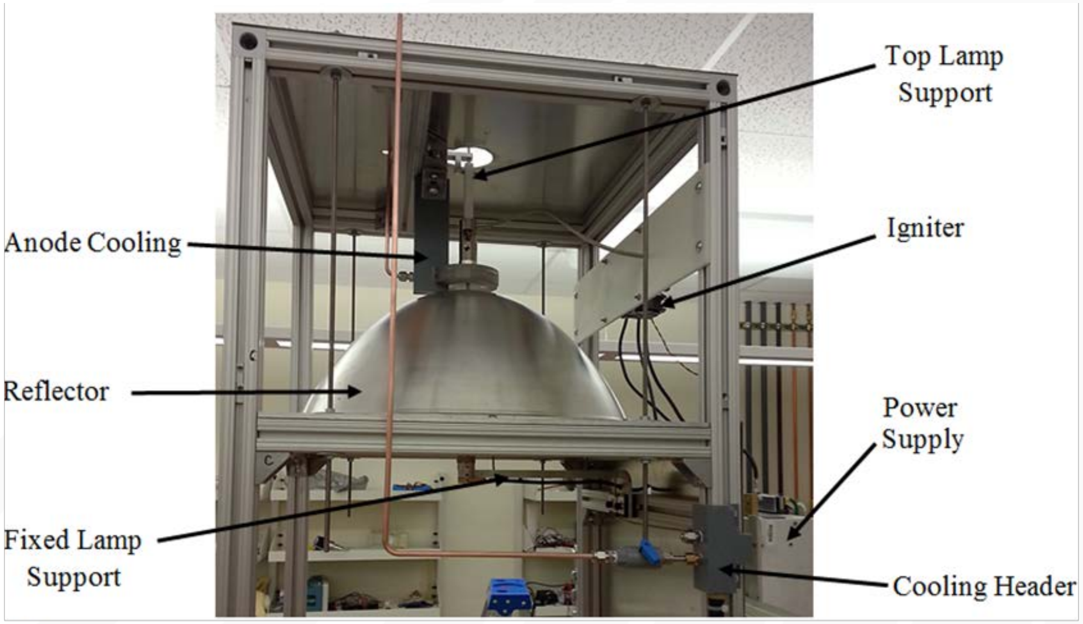




(a) (b)

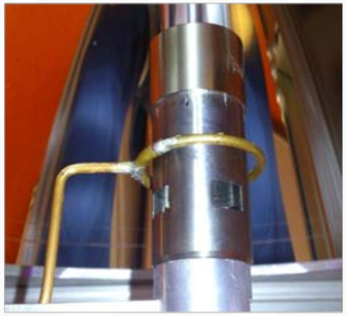
Option III design: (a) Mass flow rate per channel versus channel position. (b) Temperature contour in solid around channels. Flow is into page, solar flux is incident on bottom edge.

High Flux Simulator



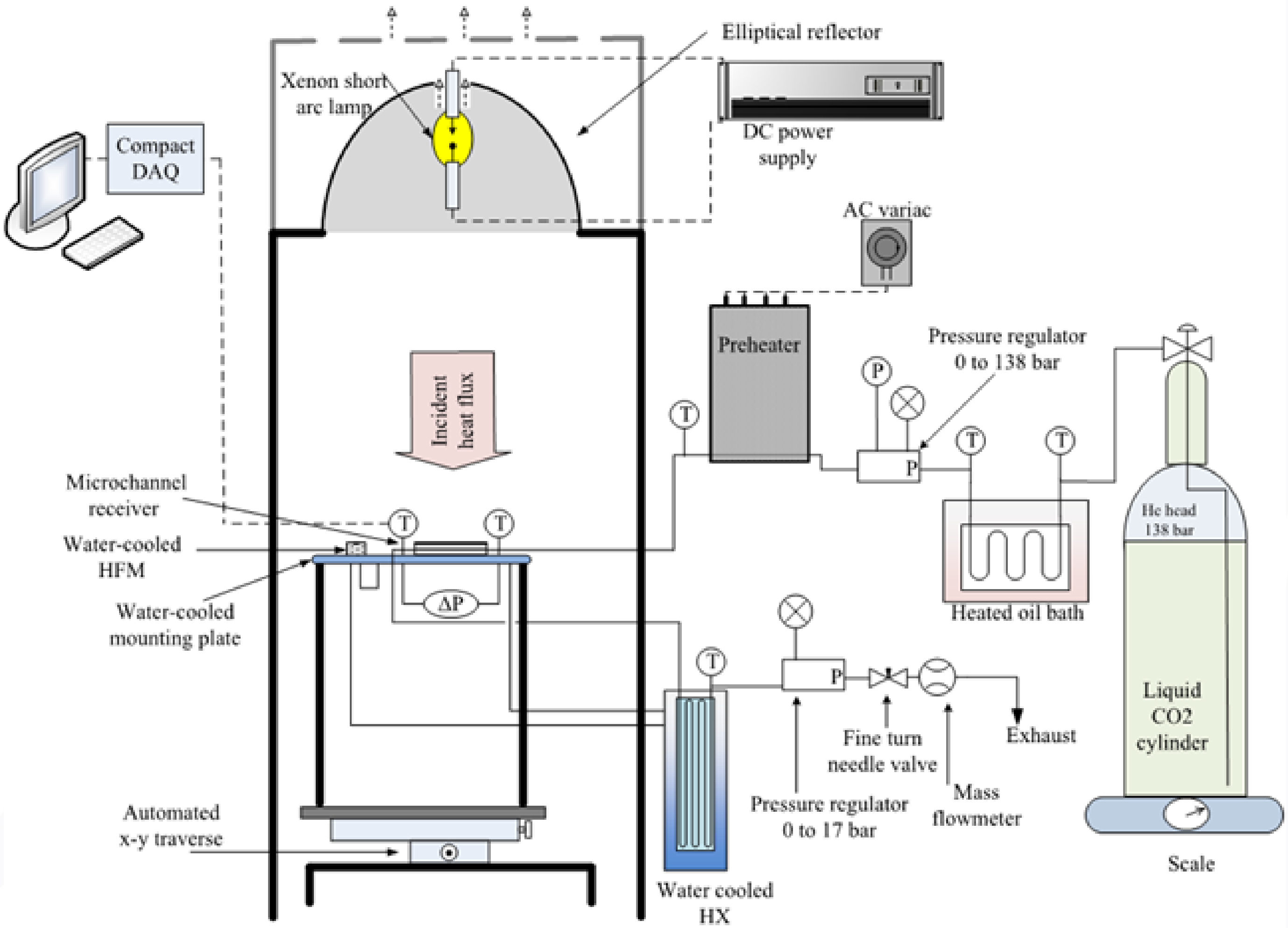
(a)

(b)

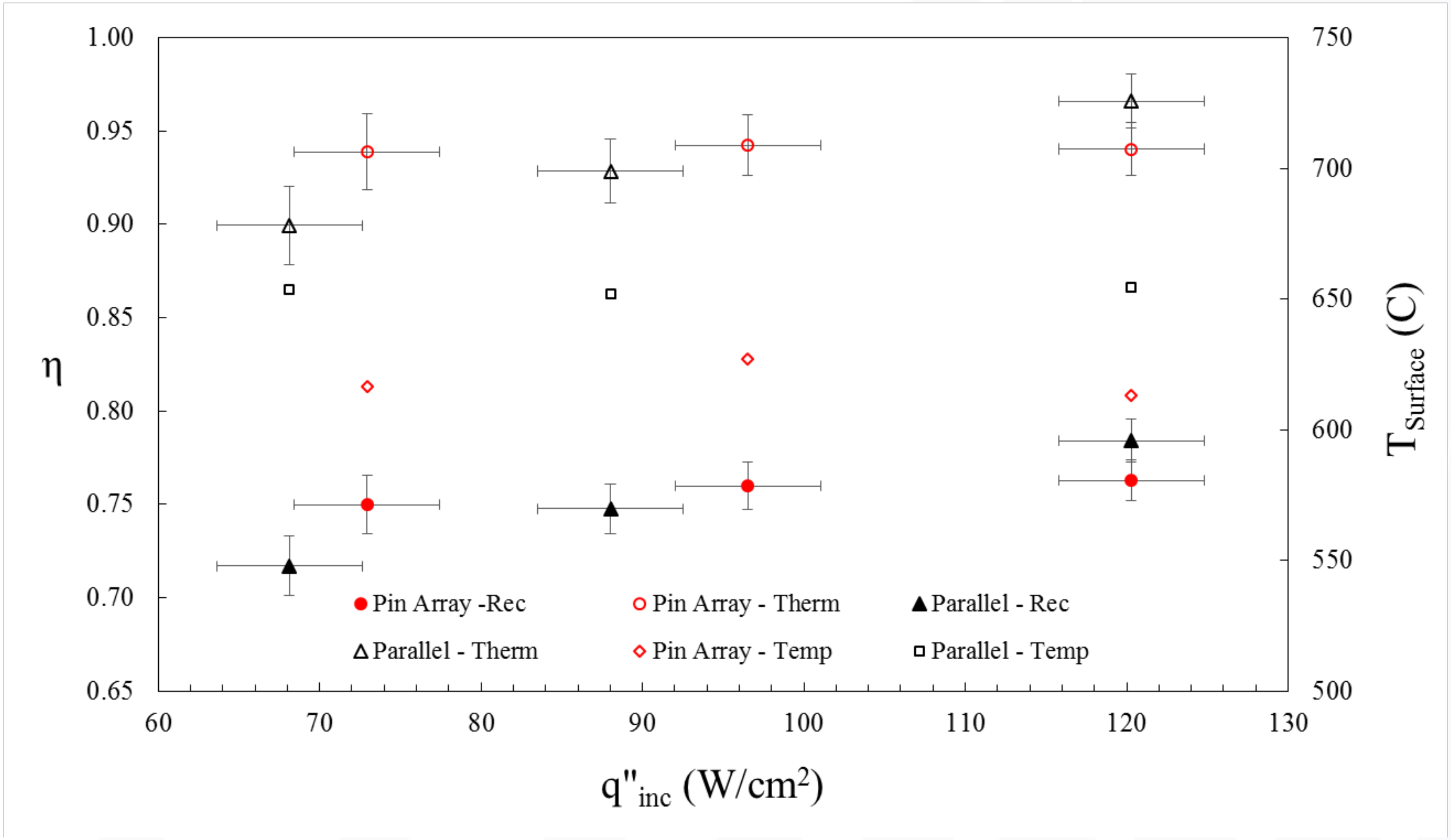


(c)

sCO_2 Facility

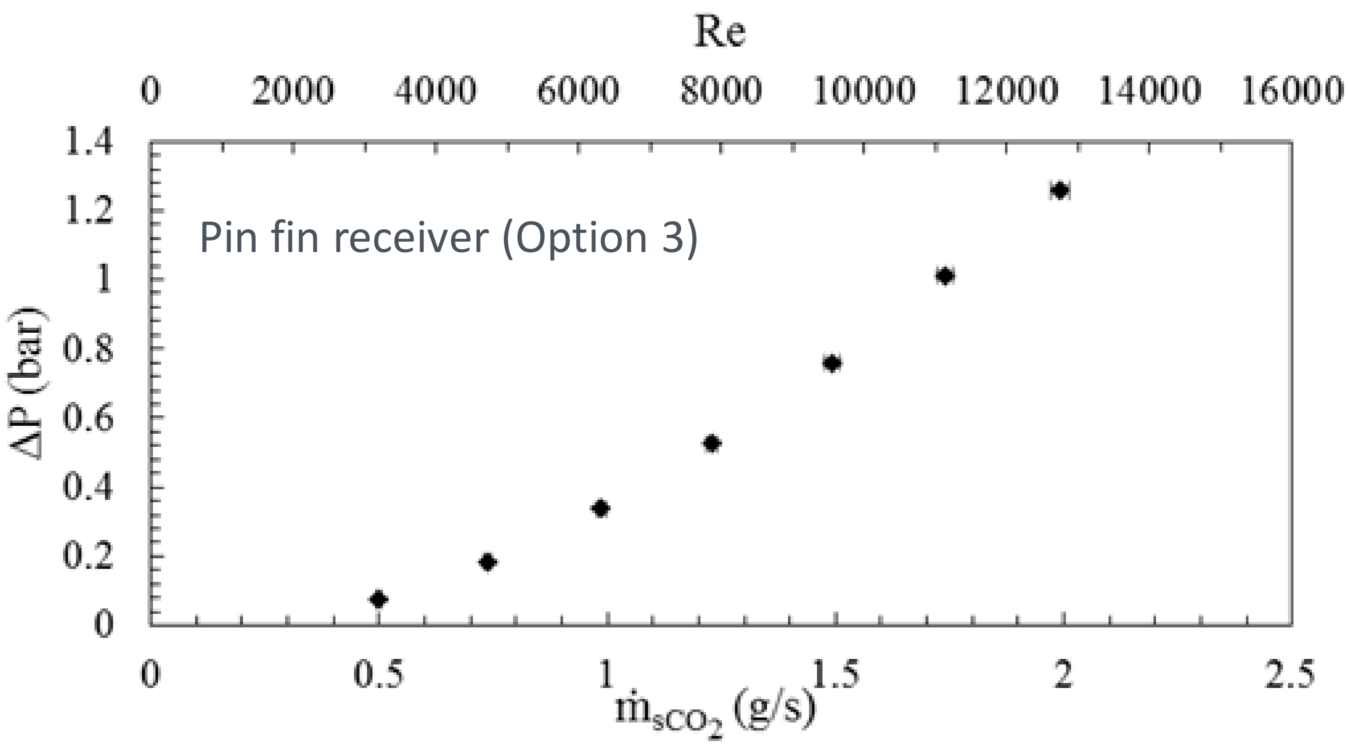


sCO_2 Receiver Results-η vs $q_{incident}$



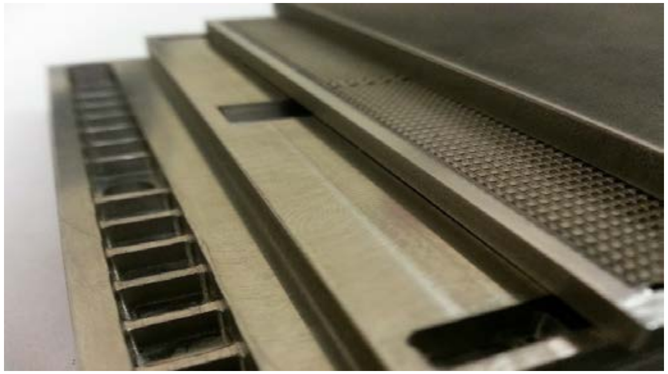
Receiver and thermal efficiency with variation of incident flux at a fixed exit temperature of ~ 650°C.

sCO_2 Receiver Results-Pressure Drop

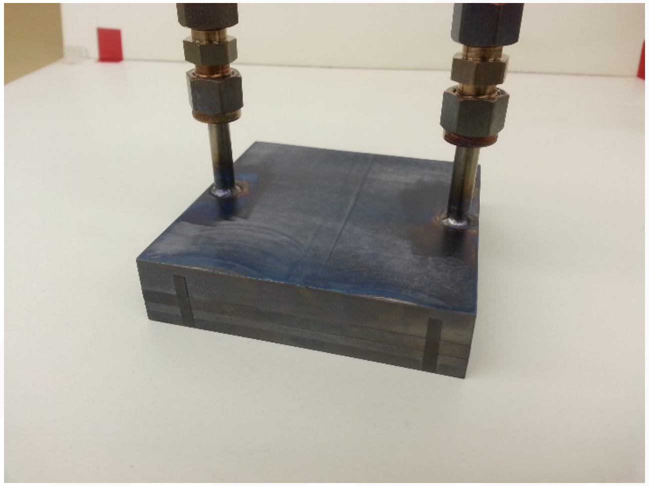


For typical heat transfer experiments, with flow rate ~ 1 g/s, the pressure drop across the receiver is under 0.5 bar

Integrated Test Article Design and Fabrication

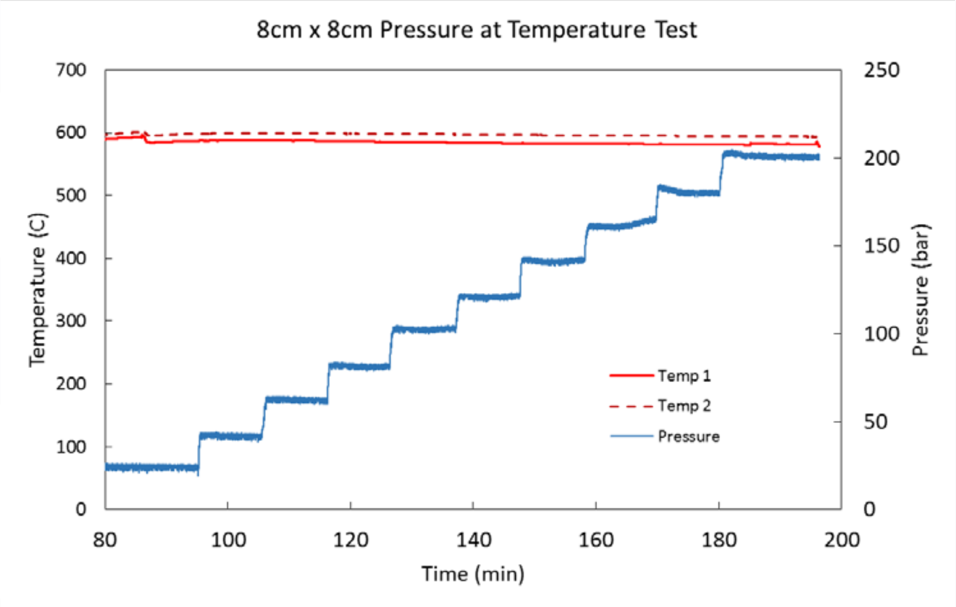


Revised Integrated Test Article

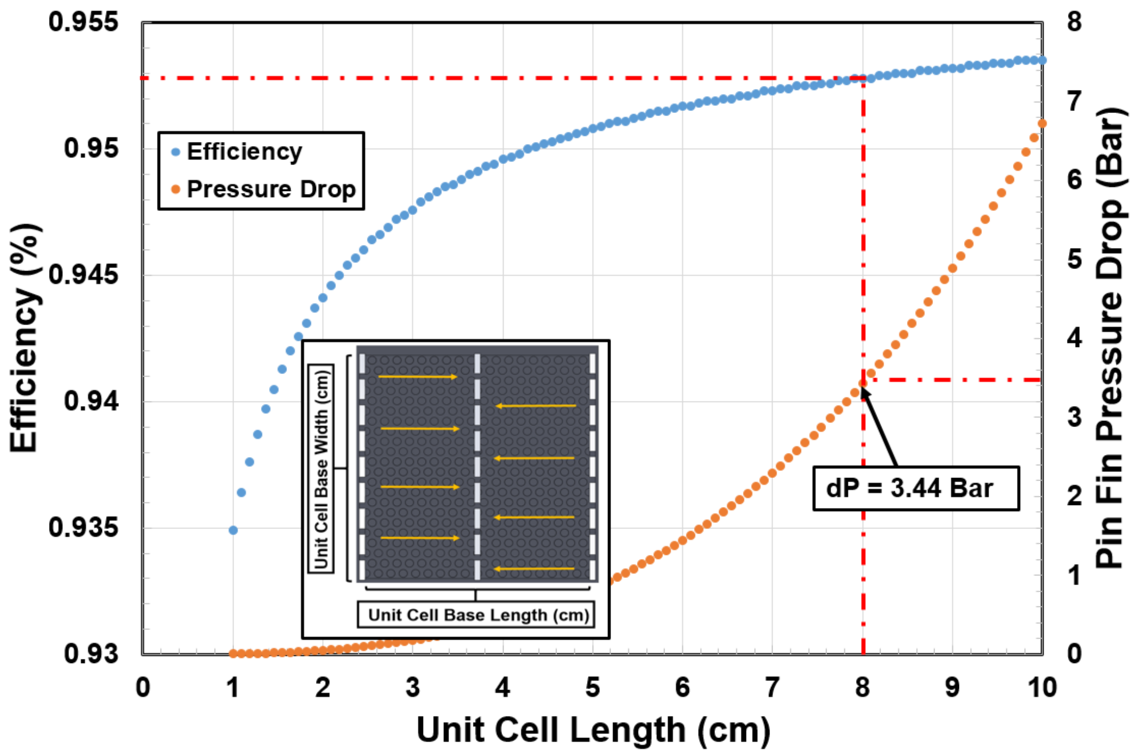


Post test Integrated Test Article

The revised test article successfully past the pressure test at temperature



Unit Cell Optimization



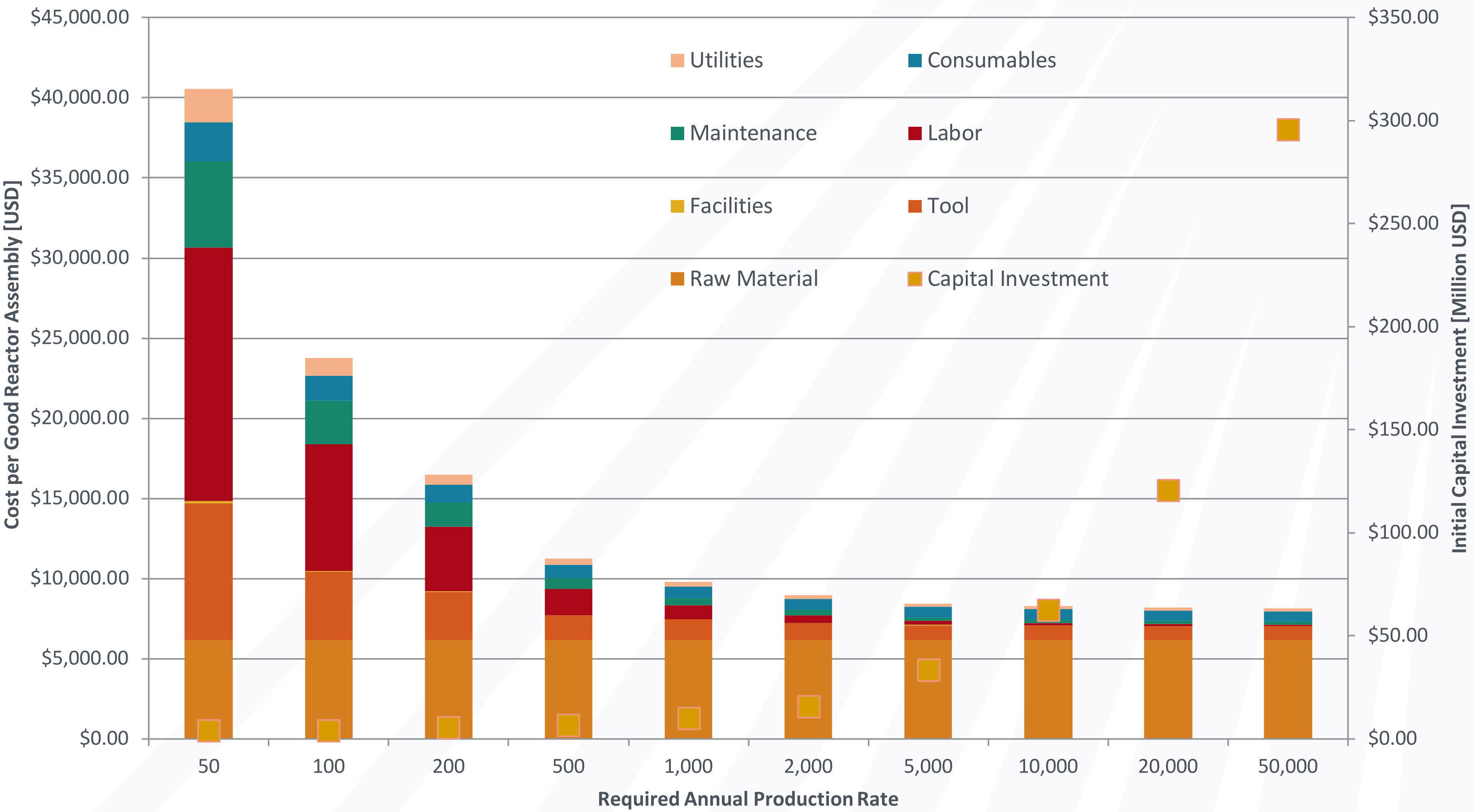
- Unit cell dimensions limited by Δ*P* (< 4 bar total)
- Larger unit cell → reduced fluid connections
- **Selected 8 ×100 cm unit cell → 12 unit cells per module**
- **0.96 m² area per module**

Receiver Structural Analysis

- Solar receiver designed to accommodate 250 solar panels and plumbing
  - 8 m diameter
  - 10 tall
- Modular design and shop fabrication for shipment on a single truck
- Assembled on-site and lifted into place
- Weight: 24,300 lbs

Structural Material	Haynes 230
Structural Weight (Structure Only)	24,300 lbs
Structural Weight (with Modules and Piping)	35,000 lbs
Estimated Structural Costs	$636,000
Material Cost Per Kilowatt	$2.54/kW

Costing Results Breakout



Path to Market

- Our Sunshot Apollo project is focused on moving the MSR from TRL 3 to TRL 5.
- Technology has other applications outside of CSP
- Commercialization will be accomplished through our commercialization partner ECOKAP
- Commercialization objective for this project is
  - 1) Completion of successful on sun test of commercial scale receiver module
  - 2) Completion of a detailed commercialization plan
  - 3) Protect Intellectual Property