

# **Multilayer Silicon Carbide Composite Material Technology for High- Temperature Concentrated Solar – Thermal Power Components**

DOE Receiver & Reactor Workshop

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## DOE-SETO Development:

- Advance fabrication technology for CSP receiver
- Material Evaluation
  - Solar properties
  - Mechanical properties
  - Corrosion resistance
- Component development
  - Joining technology
  - Component assembly



## Ceramic Tubular Products:

- Small Business formed in 2006
- Focused on material development
  - Multilayer SiC Tubing
- Applications
  - High temperature CSP components
    - Receiver, heat exchanger, pipe
  - Nuclear ATF Cladding



## Key SiC Parameters

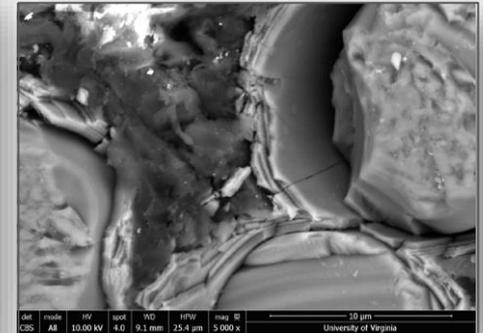
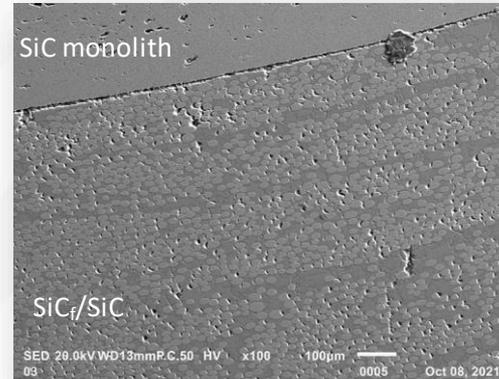
- Inner tube hermiticity (high pressure liquids and gases)
- Very high wear resistance
- High fracture toughness
- Thermal & mechanical shock resistance
- Low coefficient of thermal expansion
- Maintain high temperature properties up to 1000 °C
- Heating rates > 200 °C / minute
- High solar optical absorptance (>0.97)
- Resistant to chemical attack
  - Chloride salts
  - Supercritical CO<sub>2</sub>
  - Liquid sodium and lead
  - Oxidation



SETO Receiver Tube



ATF Cladding



CTP Technology ideal for GEN3 CSP and other high temp harsh environments

# CTP Composite Fabrication



- 30" Dia
- 12' Long



Filament Winding



- 5' Long
- Anticipate 12' long furnace in 2024

- 20" x 20" x 48"
- Expandable Length
- 12' long in 2024

Matrix Infiltration



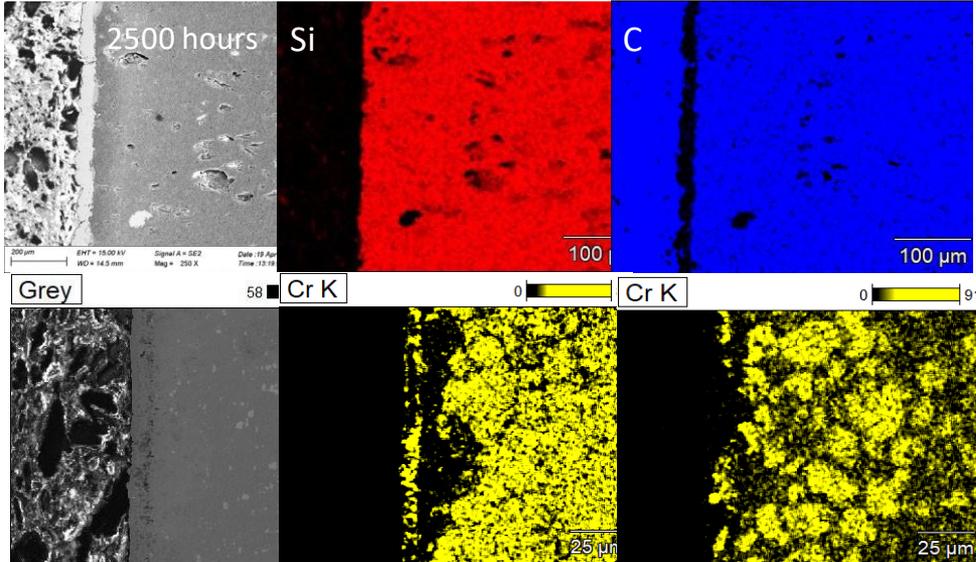
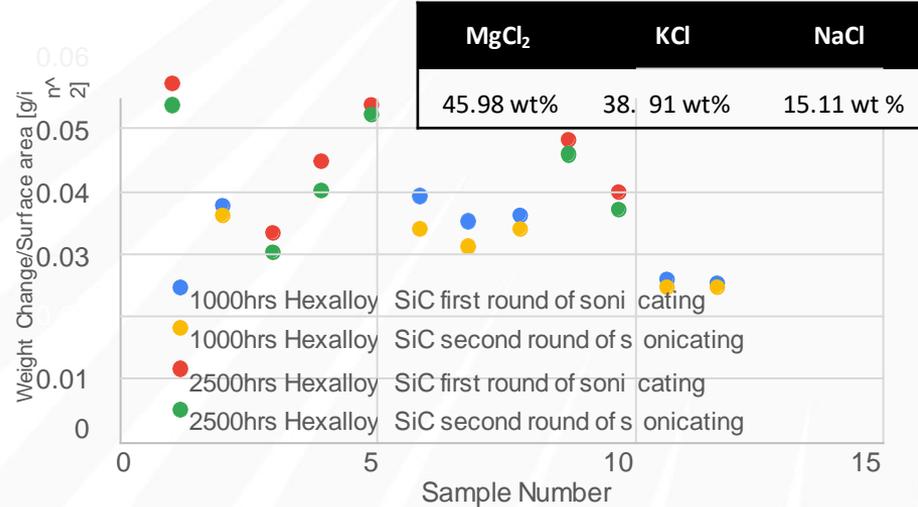
# CTP Technology for Gen3 Application Feasible

- Project focused on molten chloride salt performance
  - No corrosion of SiC
  - Withstand thermal and mechanical shock
  - High optical absorptance with no degradation over time
  - SiC joining hermetic to helium leak detection
- Developed detailed production cost assessment
  - SETO 2030 cost target for CSP plants: \$0.05/kWh
    - CTP technology supports cost goals
      - ✓ Lower capital cost
      - ✓ Lower O&M cost
      - ✓ Supports lower overall LCOE cost



Advances in CTP technology adaptable to other HTF & components

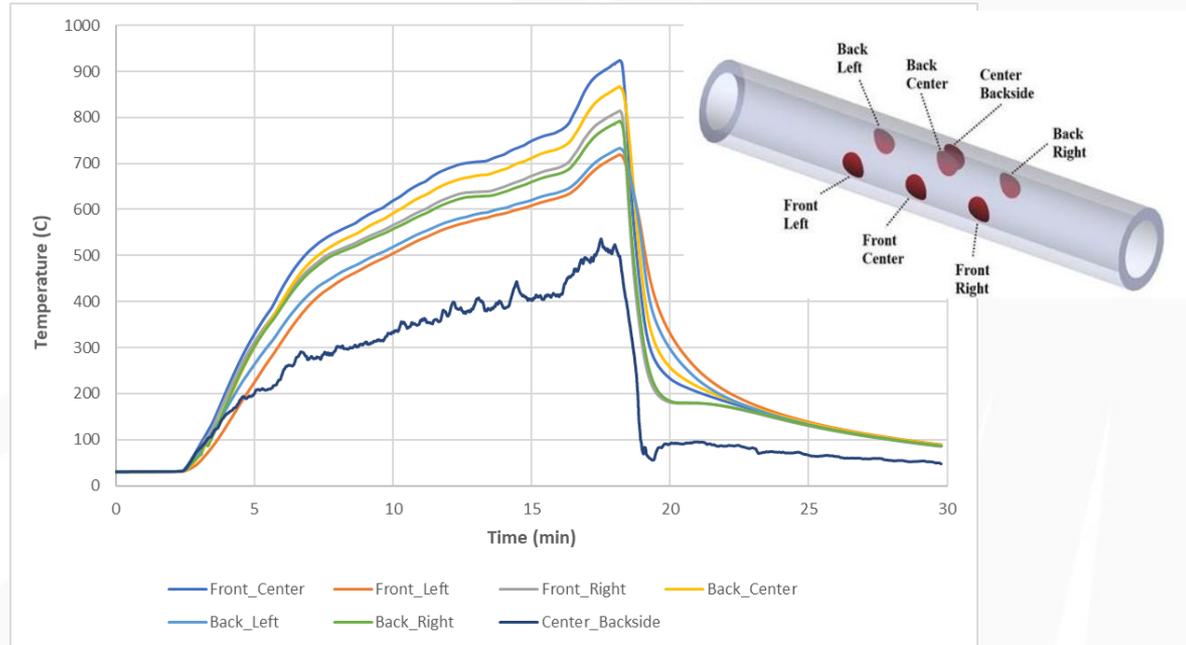
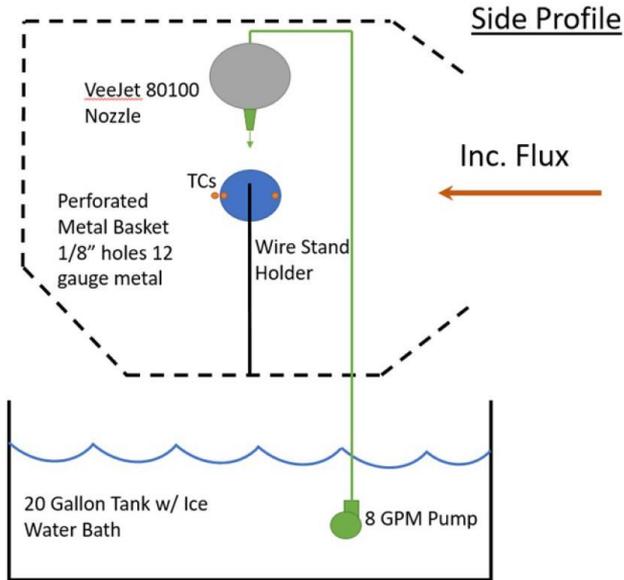
# Chloride Salt Corrosion



- **SiC:** No dissolution or salt diffusion within SiC was observed at 800 C for up to 2500 hours.
- SiC average weight gain after 2500 hours was 29 mg/in<sup>2</sup>, due to salt adhesion on SiC surface during cooling.
- **Haynes 230:** Salt-induced porosity at interface due to Cr-dissolution and grain boundary attack increased with time.
- Average weight loss of 191 mg/in<sup>2</sup>, a 6.5X increase from that of at 1000 hours (29 mg/in<sup>2</sup>).

No corrosion noted after 2500 hours at 800 °C

# Thermal Shock Performance of Receiver Tubes

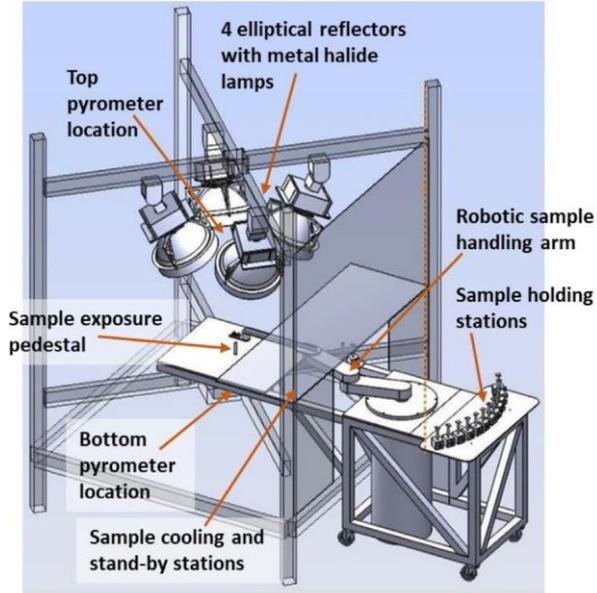


- ❑ Flux level was approximately 116 W/cm<sup>2</sup>, characteristic of CSP power tower facility.
- ❑ Simulated raindrops diameter: 2-4 mm at operating pressure of 6 psi.
- ❑ Thermal shock resistance at 900, 1000, 1100 °C using Sandia's rain drop stimulator.
- ❑ No visible cracks or damages on the SiC composite receiver tubes.

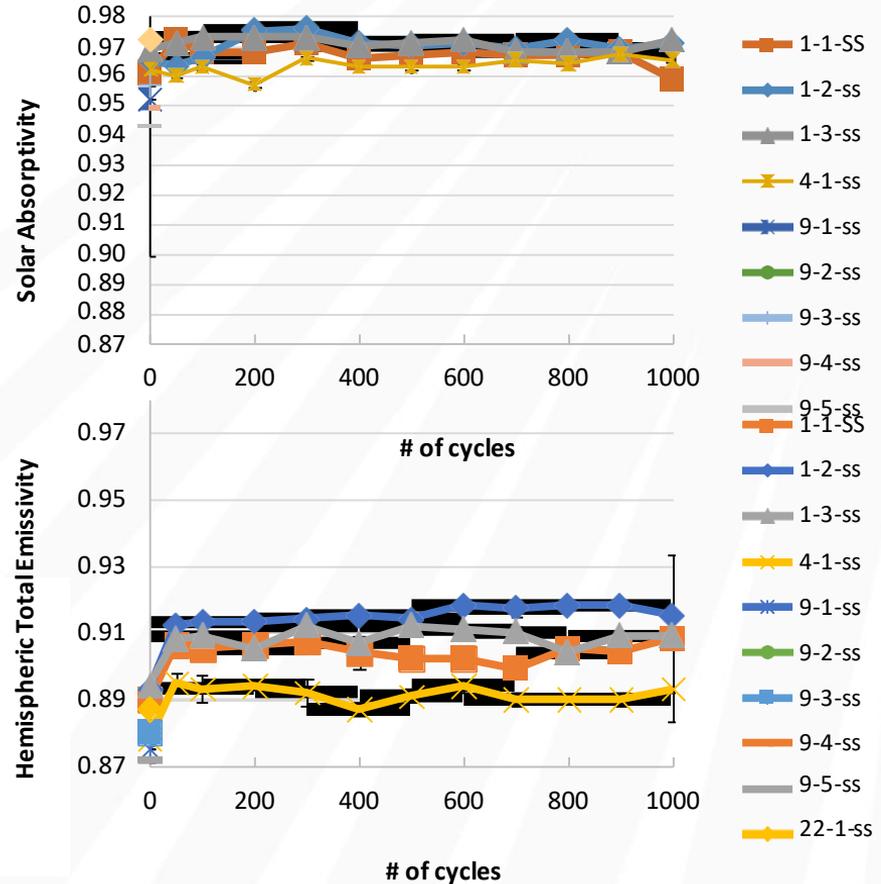
**No strength degradation after thermal shock to 1100 °C**

# Solar Optical Performance

Sandia's High Flux Solar Simulator



- ❑ Accelerated aging at 350 suns at 50-1000 cycles
- ❑ The average absorptivity: 0.97
- ❑ The emissivity range: 0.89-0.91
- ❑ Stable absorption and emittance at 800C with no cyclic degradation for up to 1000 cycles

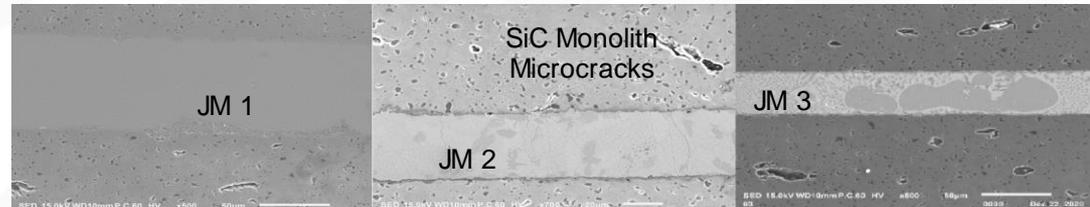


# Component Joining

- Various materials investigated for SiC-SiC joining
  - Three compounds investigated as part of this project
    - Hermetic joints achievable (helium leak test)
    - Acceptable room and elevated temperature strength
    - Minimal corrosion of 2 materials after 2500 hours in molten chloride salt
  - Other compounds continue to be investigated
    - Lower variability
    - Lower production temperature
    - Lower cost

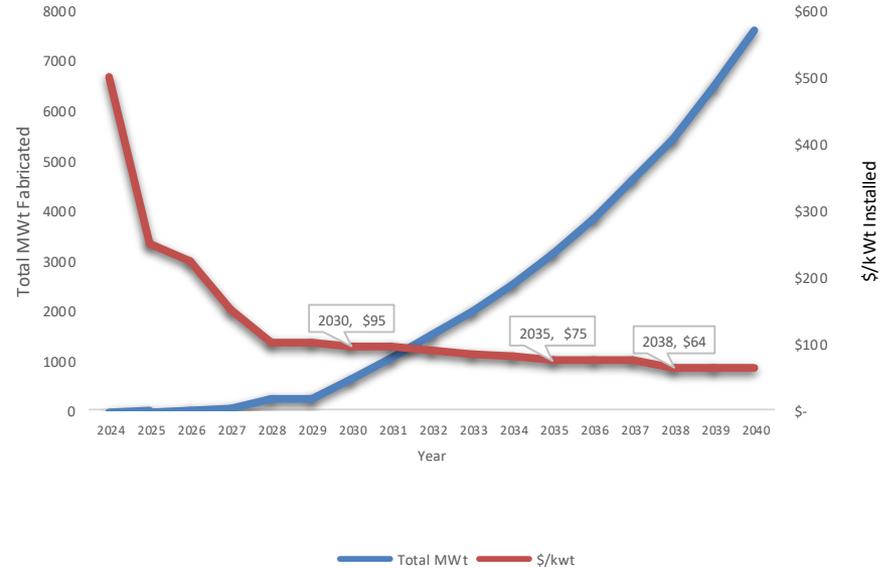


Typical Joint Samples



Joint Microstructure

- Comprehensive cost analysis for production
  - Assumed 1,000 MWt/year
  - Based on preliminary design
  - Component & commodity quantities calculated
  - Site-specific back plane budget allowance of \$3,000,000 included
  - Staffing, subcontracts, travel, special tooling, etc. included in estimate
- <\$75/kWt achievable for CSP liquid receiver
  - Higher volume production
  - Increase supply chain capacity



# Summary & Current Status

- SiC CSP receiver feasible with CTP multilayer tubes
  - High solar optical absorptance (>0.97)
  - Thermal shock resistance, (up to 1100 °C)
  - Mechanical shock resistance
  - Low coefficient of thermal expansion
  - Maintain high temperature properties
  - Corrosion resistance up to 2500 hours
    - chloride salts (at 800 °C)
    - liquid Na, with low oxygen content
  - Prototype receiver designed and fabricated
- Additional work identified to further reduce risk



Enhanced performance and lifetime at lower cost for CTP's SiC receiver relative to high nickel alloys

- Continue work to mitigate CSP risks
  - Improve CMC thermal conductivity to improve efficiency
  - Advance development of joint configuration, materials, technology
  - Advance receiver assembly process
    - Reduce manufacturing risk of large, complex ceramic components
  - Perform additional high temperature component testing
    - Multilayer SiC tube creep
  - Perform on-sun receiver testing
  - Initiate ASME code development
- Expand adoption of technology to other components & HTF
- Expand collaboration with OEMs and project developers

CTP technology ready to support CSP deployment – NO SHOW STOPPERS



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