10 MW Supercritical-CO$_2$ Turbine Project

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SunShot Program Review
April 23-25, 2013
Phoenix, AZ
# Project Summary

**Award:** DE-EE-0001589  
**Title:** 10 MW s-CO$_2$ Turbine Test  
**Overall Budget:** $16 million ($8M DOE, $8M industry)  
**Start date:** October 1, 2012

<table>
<thead>
<tr>
<th>Phase</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
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</thead>
<tbody>
<tr>
<td>Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9 Q10 Q11 Q12 Q13</td>
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<tr>
<td>Phase 1 – Design</td>
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<td>Phase 2 – Fabrication</td>
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<tr>
<td>Phase 3 – Operation</td>
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10 MW s-CO₂ Turbine Test

**Goal:** Design, fabricate, and validate a supercritical-CO₂ (s-CO₂) power cycle of nominally 10 MWe that is capable of operation at up to 700°C under dry cooling conditions.

**Innovation:** Demonstrate the inherent efficiencies of the s-CO₂ power turbine and associated turbomachinery at a design and scale relevant to commercial power generation.
## 10 MW s-CO$_2$ Turbine Team

<table>
<thead>
<tr>
<th>Partner</th>
<th>Roles and Responsibilities</th>
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<tbody>
<tr>
<td><strong>NREL (prime)</strong></td>
<td>Project management s-CO$_2$ cycle modeling; annual simulations and LCOE estimates</td>
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<td>Operation staff support</td>
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<td><strong>Abengoa Solar</strong></td>
<td>Integration of s-CO$_2$ into CSP commercial systems</td>
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<td>Analysis of market for s-CO$_2$/CSP</td>
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<td>Heat input system and heat rejection system design and fab operation staff support</td>
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<tr>
<td><strong>Echogen Power Systems</strong></td>
<td>Turbomachinery and test loop system design</td>
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<td>Compressor and turbine fabrication; Test loop system fabrication</td>
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<td></td>
<td>Analysis of market for s-CO$_2$ power systems</td>
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<td>Operation utilities and staff support</td>
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<tr>
<td><strong>Sandia</strong></td>
<td>Site preparation, system installation and operation</td>
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<td>Recompression loop test operations at high CIT</td>
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<tr>
<td><strong>UW-Madison</strong></td>
<td>Materials of construction, corrosion assessment</td>
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<tr>
<td><strong>Barber-Nichols</strong></td>
<td>System design consulting; Component manufacturing as needed</td>
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<tr>
<td><strong>EPRI</strong></td>
<td>Tech. promotion and identification of potential comm. projects</td>
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<td></td>
<td>Materials selection assistance to UW-Madison</td>
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Project Objectives

1. Design and fabricate s-CO$_2$ power turbine using conventional, scalable system design
2. Construct ~10 MWe recuperated s-CO$_2$ test loop
3. Run loop at temperatures up to 700°C
4. Test cycle operation at high compressor inlet temps (i.e., dry-cooled conditions)
5. Validate performance models with experimental data
6. Simulate annual operation of system configurations that achieve SunShot goals
7. Advance technology to commercial demonstration
Why 10 MWe Scale?

- 10 MW allows use of commercial design technologies
- Axial turbine design chosen to facilitate scale-up to larger capacity

<table>
<thead>
<tr>
<th>Feature</th>
<th>0.3</th>
<th>1.0</th>
<th>3.0</th>
<th>10</th>
<th>30</th>
<th>100</th>
<th>300</th>
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<tbody>
<tr>
<td>Turbine Speed/Size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Turbine type</td>
<td>Single stage</td>
<td>Radial</td>
<td>multi stage</td>
<td>single stage</td>
<td>Axial</td>
<td>multi stage</td>
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<tr>
<td>Bearsings</td>
<td>Gas Foil</td>
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<tr>
<td>Bearsings</td>
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<td>Hydrodynamic oil</td>
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<td>Seals</td>
<td>Adv Labyrinth</td>
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<tr>
<td>Seals</td>
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<tr>
<td>Freq/alternator</td>
<td>Permanent Magnet</td>
<td></td>
<td></td>
<td></td>
<td>Wound, Synchronous</td>
<td></td>
<td></td>
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<tr>
<td>Freq/alternator</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Shaft Configuration</td>
<td>Dual/Multiple</td>
<td></td>
<td></td>
<td></td>
<td>Single Shaft</td>
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[Diagram showing different features and technologies at various power levels]
Project Tasks

Phase 1 - Design
  1.1 Corrosion and Materials Analysis
  1.2 Detailed Test Plan Development
  1.3 Test Loop Design
  1.4 Modeling and Simulation of Cycles
  1.5 Commercial Power Cycle
  1.6 CSP Commercial Deployment Path
  1.7 Site Preparation

Phase 2 - Fabrication & Installation
  2.1 Corrosion and Materials Analysis (cont.)
  2.2 Test Loop Construction
  2.3 Installation & Checkout
  2.4 Modeling & Simulation
  2.5 Conceptual Design Study of Commercial CSP System

Phase 3 - Operation & Simulation
  3.1 Corrosion and Materials Analysis (cont.)
  3.2 Low-temp operation (550C)
  3.3 High-temp operation (>650C)
  3.4 System Model Validation
  3.5 Response and Control of Recompression Cycle

Project Management & Reporting
Alloy Corrosion Tests (UW-Madison)

200 hours exposure to CO₂ at 650°C and 200 bar:

<table>
<thead>
<tr>
<th>Alloy</th>
<th>C</th>
<th>Fe</th>
<th>Cr</th>
<th>Ni</th>
<th>Mn</th>
<th>Nb</th>
<th>Mo</th>
<th>Si</th>
<th>Cu</th>
<th>Co</th>
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<tr>
<td>316L</td>
<td>0.045</td>
<td>64.3</td>
<td>17.4</td>
<td>13.3</td>
<td>1.7</td>
<td>-</td>
<td>2.7</td>
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<tr>
<td>347ss</td>
<td>0.051</td>
<td>68.5</td>
<td>17.7</td>
<td>9.62</td>
<td>1.66</td>
<td>0.72</td>
<td>0.38</td>
<td>0.77</td>
<td>0.38</td>
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347 SS Surface SEM

No Large Oxidation Cluster

Oxide particles

Smaller grainy oxide
347 SS Elemental Analysis via EDS

Nb oxide particles
Initial Results: 347 and 316L

1. 316L shows higher weight gain than 347ss despite their similar composition.

2. The major oxide is large Fe oxide clusters in 316L and Nb oxide particles in 347ss. Small grainy Mn-rich oxides found in both alloys, but their number density is higher in 347ss than in 316L.

3. The reason for formation of different oxides in these two similar alloys is still being investigated.

4. Other alloys under analysis: Inconel 800H, Haynes 230, AFA-O6C
The SunShot test hardware consists of:
Echogen EPS100 System with high-temp turbine, high-temp recuperator, and modified compressor + 700C heat source + dry cooling system

Echogen’s first-of-kind EPS100 process skid being transported for testing.
Test Site

Testing will occur at Sandia National Laboratories’ Nuclear Energy Systems Lab (NESL), host site for Brayton cycle research.
Site Preparation

Nuclear Energy Systems Lab (NESL)

- Air-cooled HX location
  ~6000 sq. ft
- Offices
- Highbay for 10 MW turbine skids
- DOE-NE Brayton systems lab
- DOE-NE recompression loop
SunShot Path for s-CO$_2$ Brayton Cycle

Contributions under the 10 MW s-CO$_2$ Turbine project are highlighted in orange.

- **Cycle**
  - Lab-scale proof of concept
  - Commercial turbine design
  - Cycle control

- **Materials**
  - Materials testing
  - Operation at 550°C

- **Solar**
  - Dry cooling
  - Solar Receiver / HXC Design
  - Solar component testing
  - On-sun testing

- **Commercial Applications**
  - Solar, Waste-heat, Fossil, Nuclear

- **Long-term testing & materials certification**

- **Adv. commercial power cycle**

- **CSP SunShot**

- **Commercial demo plant**

- **Operation at 500°C**

- **Operation at 700°C**