The world’s largest solar thermal project

- Size: 3,600 acres
- Power Production: 370 MW (nominal)
- Homes Served Annually: 140,000
- Customers: PG&E and SCE
- Owners: NRG, Google, BrightSource
- DOE Loan Guarantee: $1.6B
- Project Financing: $2.2B

- Construction Commenced: Oct 2010
- Construction Status: 50% + complete
- Construction workers: 2,000
- Expected Completion: 2013 (Q2 – Q4)
Concentrated Solar Power Overview

1. **Heliostats**
   - Concentrate heat on a boiler mounted in the solar receiver

2. **Solar Receiver**
   - Concentrated sunlight converts water in boiler to steam

3. **Turbine**
   - Steam powered turbine produces electricity

4. **Thermal Storage**
   - Integrated, cost-effective thermal energy storage

5. **Grid**
   - Electricity transmitted to the grid
Overview

IVANPAH PROJECT SITE

133 MW
60,000 Heliostats

133 MW
60,000 Heliostats

126 MW
53,500 Heliostats

Heliostat

SRSG (Boiler)
Concentrated Solar Power Main Components

**TURBINE**
Steam powers turbine to produce electricity – then is converted back to water through an air-cooled condenser.

**SOLAR RECEIVER / BOILER**
Concentrated sunlight converts water in a boiler to high-temperature steam.¹

**HELIOSTATS**
Software-controlled field of mirrors concentrate sunlight on a boiler mounted on a central tower.

**AIR-COOLED CONDENSER**
Low-impact design, using over 90% less water than competing solar thermal technologies that use conventional wet-cooling.

**AUXILIARY GAS-FIRED BOILER**
Allows for hybridization, increased output and the enabling of more reliable electricity production.

**OPTIMIZATION / CONTROL SOFTWARE**
Proprietary optimization software and Solar Field Integrated Control System manage heliostat positioning to optimize concentrated sunlight on the boiler.

**STORAGE**
When integrated, cost-effective thermal energy storage extends solar electricity production into later parts of the day after the sun goes down.
Play “Fly by” of Power Block
- Top of Solar Receiving Steam Generator (SRSG) = 450 feet
- Top of Steel Structure = 327 feet
- 7,533 tons of steel
- 9 tower tiers
  - Tiers 1 – 4 = Stick built
  - Tiers 5 – 9 = Modularized, including pipe & hangers

Tuned Mass Damper to reduce tower movement = 100 tons
SRSG – Inside out, upside down boiler

- Insulation Panels
- Superheater Section
- Evaporative Steam Generation Section
- Reheater Section
- Insulation Panels
Elevation Difference from Unit 3 to Unit 1 is 300 feet at 3.5% grade.

Distance = 1.48 miles
Driving distance = 2.83 miles

Distance = 1.81 miles
Driving distance = 2.19 miles

Aerial of Ivanpah Site
Unit 1 Construction Progress
## Construction Progress

<table>
<thead>
<tr>
<th></th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tower</strong></td>
<td>At final height of 459’</td>
<td>At final height of 459’</td>
<td>At final height of 459’</td>
</tr>
<tr>
<td></td>
<td>Receiver / Boiler installation in progress</td>
<td>Receiver / Boiler installation in progress</td>
<td>Receiver / Boiler installation in progress</td>
</tr>
<tr>
<td><strong>Power block</strong></td>
<td>Turbine in place</td>
<td>Turbine in place</td>
<td>Turbine in place</td>
</tr>
<tr>
<td></td>
<td>Air Cooled Condenser (ACC) construction ongoing</td>
<td>Air Cooled Condenser (ACC) construction ongoing</td>
<td>Air Cooled Condenser (ACC) construction ongoing</td>
</tr>
<tr>
<td><strong>Solar field</strong></td>
<td>Pylons: 92% complete</td>
<td>Pylons: &gt; 35,000 installed</td>
<td>Pylons: Installation scheduled to start 6 / 2012</td>
</tr>
<tr>
<td></td>
<td>Heliostats: &gt; 45,000 installed</td>
<td>Heliostats: &gt; 1500 installed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Installation rate ~ 500 / day</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solar Field Integrated Control System (SFINCS) installed</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>5/31: 1st SRSG boiler lift</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5/31: Auxiliary boiler foundation</td>
</tr>
</tbody>
</table>
Ivanpah – Original Artist Rendering

Unit 3

Unit 2

Common Area

Unit 1

Primm Valley Golf Course
Overview - Ivanpah Site as of August 2009
Overview - Ivanpah Site as of May 2012

Unit 1
Unit 2
Unit 3
Common Area
Substation (SCE)
Construction logistics area

Photo taken May 2012
Overview - Ivanpah Site as of May 2012
Overview – Ivanpah Site as of July 2012
Heliostat

- Pads
- Mirrors
- Torque Tube
- Support Arms
- Diagonals
- Elevation Drive
- Azimuth Drive
- Electronic Enclosure
Integration of supply and assembly at site
Integration of Supply and Assembly at Site
Integration of Supply and Assembly at Site
- 22,000,000 key Heliostat components
- 30,000 Ton of Heliostat support structural steel (~3 X the total metal in Eiffel Tower)
- 2,000 Km of cables (~1/6 of Earth's diameter)
- 4,000 truck loads; average of 55 per week
- Over 7,000 schedule tasks
- Import/Export via ~10 ports (Haifa, Shanghai, Ningbo, Hamburg, Bremen…)
Pylon Insertion Machine
Transportation of Heliostats to Solar Field
Installation of heliostats; 500/day
Unit 1 Solar Field looking at Unit 2 & Unit 3
Ivanpah – Current Status

- Construction is half-way complete
- Installed 27 miles of plant piping
- Assembled and installed about 100,000 pylon supports and 50,000 heliostats
- Installed 3,000 heliostats a week in the last three weeks “one-a–minute”
- Solar towers for Units 1, 2, 3 are erected
- SRSG for Units 1 and 2 are erected; Unit 3 tops out next month
- Unit 1 to enter testing and commissioning phase
Solutions for First of a Kind Challenges

- **Logistics in assembling and transporting 173,000 heliostats across 3,600-acre project site**
- **Operation and use of 3 tower cranes at 450 feet tall**
- **Only 22 of these cranes in world**
- **Lifting 90-ton modules to a height of over 300 feet**
Labor and Equipment

- Peak construction workers = over 2,000
- Project supports additional jobs throughout supply chain
- Local building trades staffing project
- More than 50% of ocean freight is shipped aboard US-flagged vessels
- Pay prevailing wages
- Construction equipment selection minimizes environmental impact
Low Impact Development

- Highly land efficient; 1/3 less land per MWh
- Provides for heliostat placement and flexible plant design to work within natural land contours
- Avoids impacts and costs of extensive land grading and concrete pads

Key design parameters:
- Water Use: dry-cooling, conservation and closed-loop recycling
  - Uses air instead of water to condense steam
  - Uses over 90% less water than CSP using traditional wet-cooling

![Chart showing water use comparison between different cooling methods]
A “Cool Project” – World’s Largest CSP

### Environmental Benefits

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000,000</td>
<td>MWh of electricity per year</td>
</tr>
<tr>
<td></td>
<td>~300 average sunny days</td>
</tr>
<tr>
<td>140,000</td>
<td>Typical U.S. homes powered per year</td>
</tr>
<tr>
<td>70,000</td>
<td>Cars off the road, per year (avoided emissions equivalent)</td>
</tr>
<tr>
<td>12,300,000</td>
<td>Metric tonnes of avoided CO₂ over 30-year life-cycle (363,000 MT/yr)</td>
</tr>
<tr>
<td>123,350 (100 AF)</td>
<td>Cubic meters of water used per year (less than 300 U.S. homes)</td>
</tr>
<tr>
<td>Less than 1%</td>
<td>Concrete surface impacted. None used with pylons. Low impact construction design.</td>
</tr>
</tbody>
</table>

Enough reflective area to cover approximately 600 football fields...enough mirrors to replace all the windows of the Empire State building...54 times.

“Ivanpah is an iconic infrastructure project that will set the course for the future of renewable energy in the US and around the world,” said John Woolard, President & CEO, BrightSource Energy.
Solar Thermal Power
Tower Technology
Solar To Steam

Yasser Dib
San Antonio
Sep 7th, 2012

brightsourceenergy.com
Introduction

BrightSource Energy designs, develops and deploys concentrating solar thermal technology to produce high-value steam for electric power, petroleum and industrial-process markets worldwide.
Chevron’s Coalinga Project - Solar-to-Steam for Thermal Enhanced Oil Recovery
Coalinga Solar-to-Steam EOR Project

Key Design Parameters:

- 29MWth for Enhanced Oil Recovery (EOR)
- 100 acres
- 98.5 meter receiver tower with boiler
- 20.5 meter boiler
- 3,822 heliostats (55,000 m² reflecting area)
- Mechanical completion / testing complete

Selected Technology Features:

- Saturated steam
- Heat exchanger
- Closed loop boiler water feed
- Ties into existing steam injection system
Chevron’s Coalinga Project - Solar-to-Steam for Thermal Enhanced Oil Recovery
## Power vs. EOR Application Differences

<table>
<thead>
<tr>
<th></th>
<th>Power</th>
<th>EOR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power Block</strong></td>
<td><strong>Power Block</strong></td>
<td>No Power Block</td>
</tr>
<tr>
<td><strong>Receiver</strong></td>
<td>Evaporated +</td>
<td>Evaporator</td>
</tr>
<tr>
<td></td>
<td>Superheated + Re-heater</td>
<td></td>
</tr>
<tr>
<td><strong>Steam</strong></td>
<td>Temperature: 560+ °C</td>
<td>Saturated Steam 300+ °C</td>
</tr>
<tr>
<td></td>
<td>Injected into the Turbine</td>
<td>Injected down the reservoir</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>160 + Bar</td>
<td>60-70 Bar</td>
</tr>
<tr>
<td><strong>Heat Exchanger</strong></td>
<td>No Heat Exchanger</td>
<td>Heat exchanger between clean water / dirty water loops</td>
</tr>
<tr>
<td><strong>Solar Field + Tower</strong></td>
<td>same</td>
<td>same</td>
</tr>
</tbody>
</table>
Technology Scale-Up

- Solar Energy Development Center (6 MWth) Operating
- Chevron Coalinga Solar Thermal EOR Plant (29 MWth) Commissioned
- Ivanpah Solar Electric Generating System (377 MW) Under Construction
- Rio Mesa Solar Electric Generating Facility (500 MW) Permitting
Increased size drives power block cost effectiveness

High temperature and increased pressure drive turbine efficiency and lower costs

Additional capacity and storage yield higher efficiency and increased asset utilization
BrightSource Power Tower Components

1. **HELIOSTATS**
   - Software-controlled field of mirrors concentrates sunlight on a boiler mounted on a central tower.

2. **OPTIMIZATION/CONTROL SOFTWARE**
   - Proprietary optimization software and Solar Field Integrated Control System (SFNCS) manage heliostat positioning to optimize concentrated sunlight on the boiler.

3. **SOLAR RECEIVER (BOILER)**
   - Concentrated sunlight converts water in a boiler to high-temperature steam.

4. **POWER BLOCK**
   - Steam powers turbine to produce electricity, then is converted back to water through an air-cooled condenser. Auxiliary boiler allows for hybridization, increasing output and enabling more reliable electricity production.

5. **STORAGE**
   - When integrated, cost-effective thermal energy storage increases solar electricity production.
Heliostats Overview

- Heliostat individually positioned to optimize annual plant output and revenue
- Dual-axis tracking significantly increases plant output, particularly in winter months and late afternoon hours of the day
- Low-impact design avoids costly extensive land grading and concrete pads

Two flat glass mirrors (2.3m x 3.3m) mounted on a single pylon equipped with a computer-controlled drive system
Proprietary Optimization Control Software Overview
Solar Field Integration and Control System (SFINCS)

- Algorithmic software determines the optimal position of each heliostat accounting for the unique conditions of each project site
- The SFINCS control system manages distribution of energy across the solar receiver using real-time heliostat-aiming and closed-loop feedback
- On-site weather systems, and visual and infrared cameras provide real-time feedback into advanced algorithms for solar field management
- Proprietary optimization and control software maximizes project performance and power production efficiencies
Solar Field Optimization

Field layout simulation calculates optimal heliostat positioning to minimize shading, and maximize heat concentration on solar receiver.

Coordinated field of heliostats enables system to achieve industry-leading steam temperature and pressure levels.
Solar Receiver Overview

**Solar Receiver Steam Generator (SRSG)**
- Utility-scale “inside out” boiler heated by reflected solar radiation
- Proprietary coatings for maximum solar energy absorption

**SRSG Infrared Image**

**SBMS Temperature Measurement**

**SOLAR RECEIVER STEAM GENERATOR (SRSG)**

**SOLAR BOILER MANAGEMENT SYSTEM (SBMS)**
- Matches steam output to load demand
- Camera and sensors transmit real-time heat levels to heliostat control system
- Flexibility to respond rapidly to cloud cover & weather changes
CSP Technology: Areas of Focus

- **Solar Field**
  - Wireless communication and control
  - Solar PV powered drives
  - Mirror reflectivity, cleaning and anti-fouling
  - Heliostat control and accuracy
  - Improved measurement devices (flux, tracking)
  - Real-time attenuation measurement and cloud coverage
  - Weather forecasting, day ahead, hours and immediate

- **Receiver**
  - Advanced “selective” coatings
  - Alternative heat transfer fluids
  - Secondary reflectors

- **Supercritical steam conditions and turbine efficiencies**

- **High Efficiency Storage Integration**
BrightSource
Limitless

brightsourceenergy.com