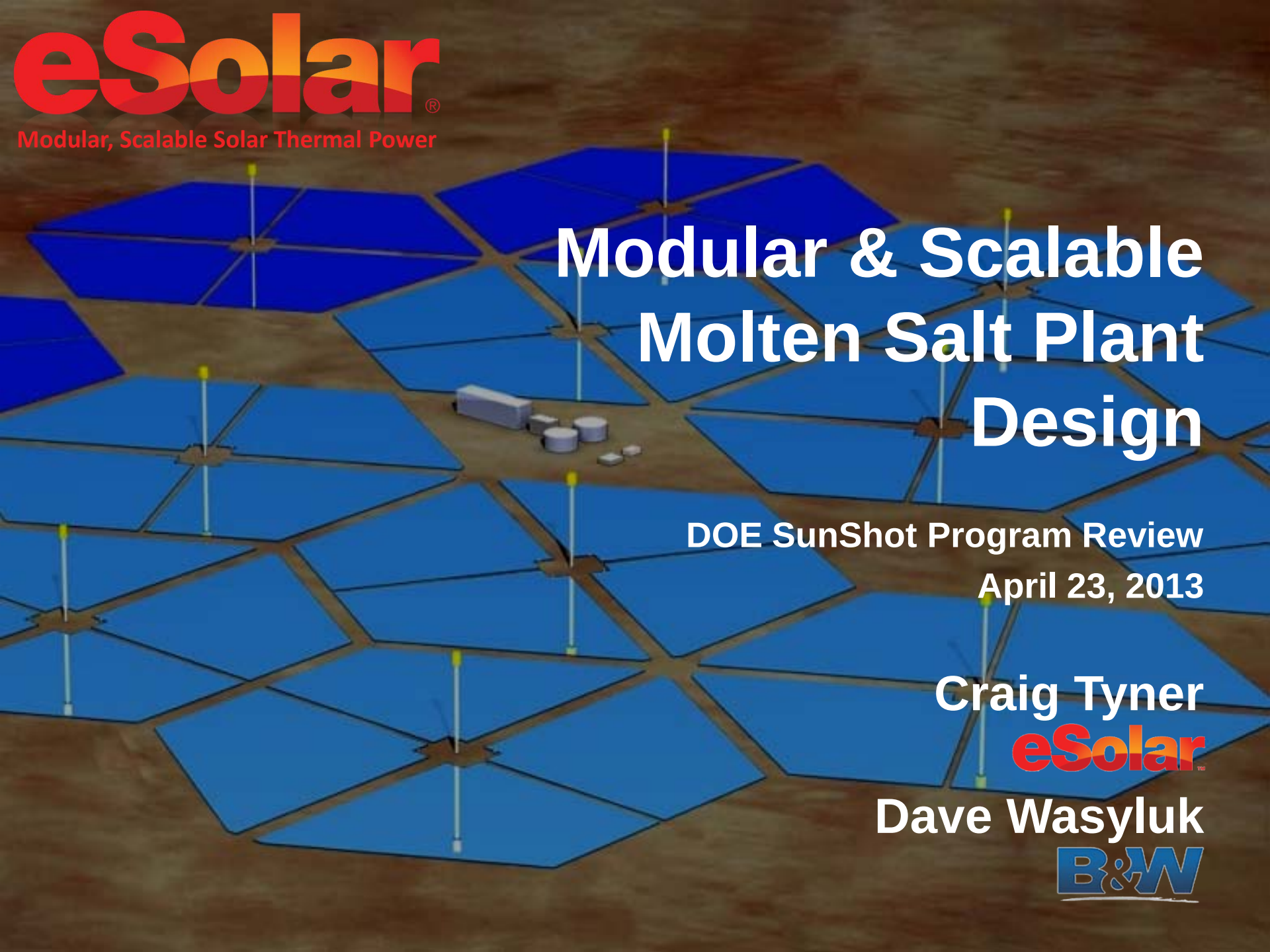
eSolar®

Modular, Scalable Solar Thermal Power



Modular & Scalable Molten Salt Plant Design

DOE SunShot Program Review

April 23, 2013

Craig Tyner

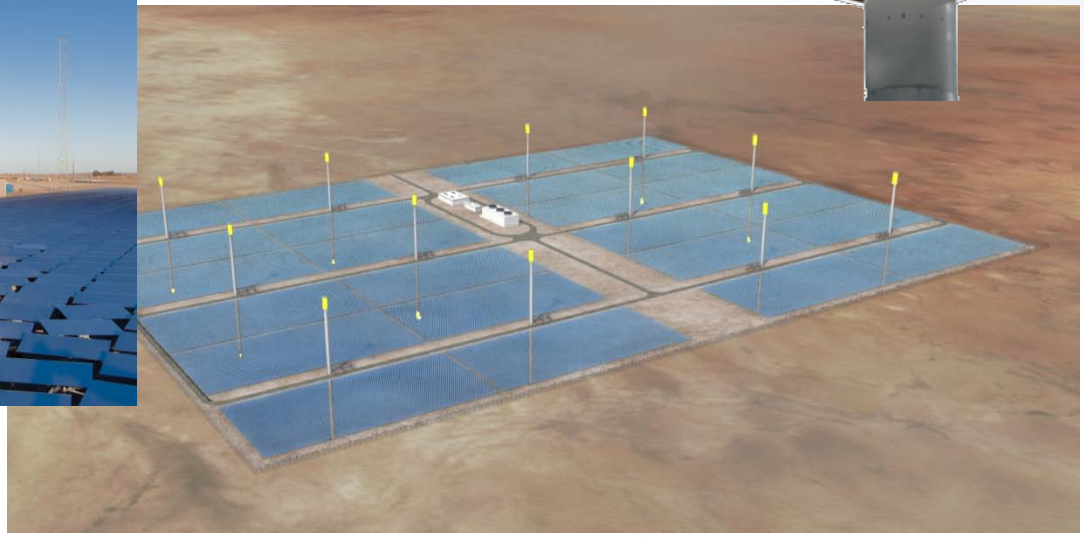
eSolar

Dave Wasyluk

B&W

Beyond eSolar's Direct Steam Technology

- 12 field/receiver/tower modules for 30% capacity factor
- B&W shippable external receiver
- No storage



Our Molten Salt Development Program

In partnership with B&W, supported by DOE "Baseload FOA"

- 100-MW plant; 75% capacity factor; Daggett weather
- No water restriction; 15% fossil contribution allowed
- 8 to 9 ¢/kWh by 2020 (in 2009$ with SAM assumptions)

- **Phase I:** System feasibility study & conceptual design
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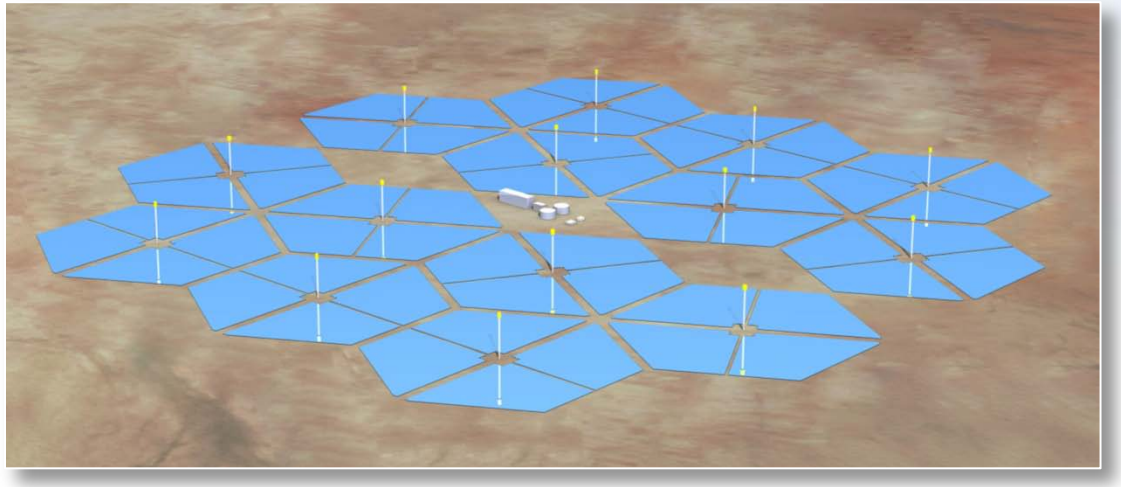
  - Not part of DOE program

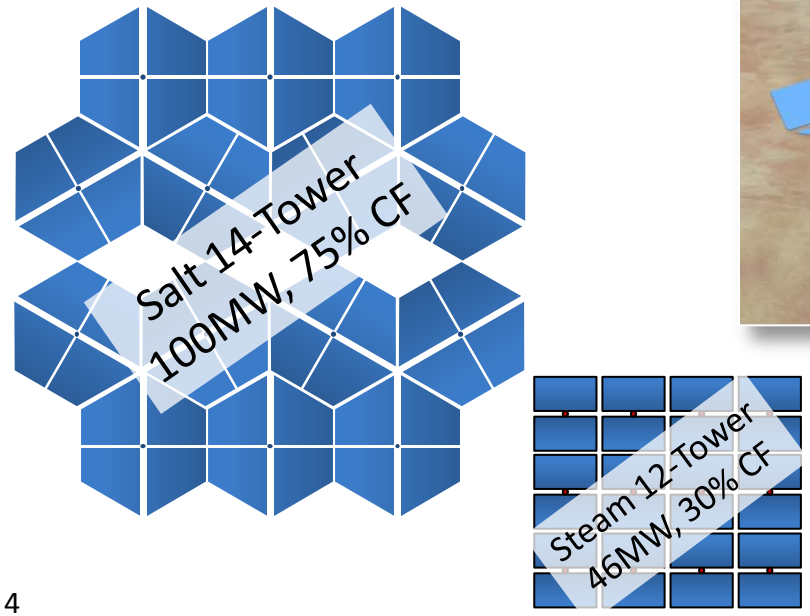
eSolar's Modular Molten Salt Plant

DOE 100-MW Baseload Configuration

- Fourteen 50-MW thermal modules on 530 hectares total land area
- Central power block
  - 13 hours thermal storage
  - 275 MW_t steam generator
  - 115 MW gross turbine generator
- Capacity factor: 75% (dry cooled (design basis)), 78% (wet-cooled)
- No hybridization

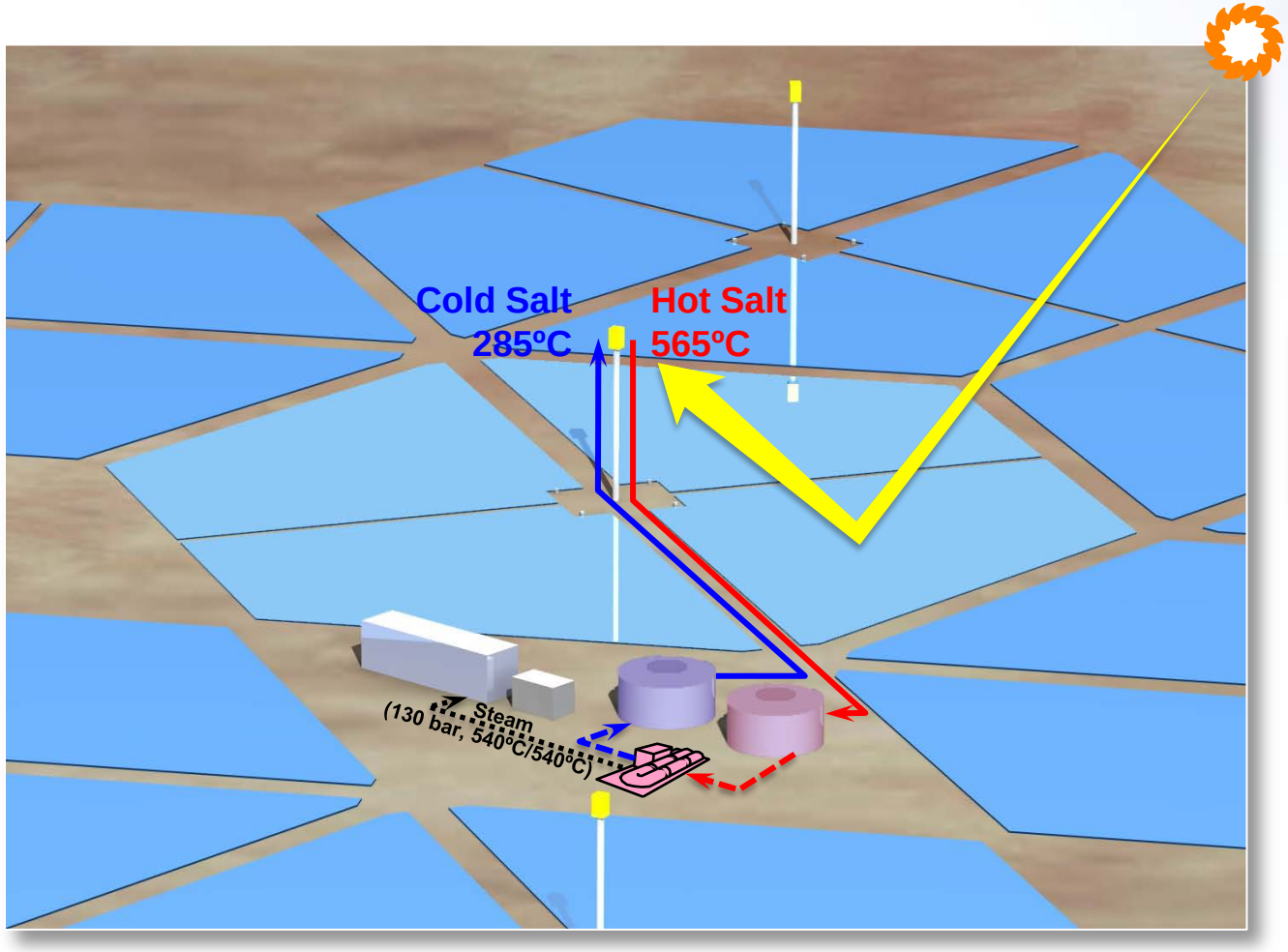


Comparative sizes:



50-MW_t Module Configuration

- Hexagonal heliostat field with 105,000 m² mirror area
- 50-MW_t B&W receiver on 100-m monopole tower



Heliostat evolution from:

SCS3 heliostats

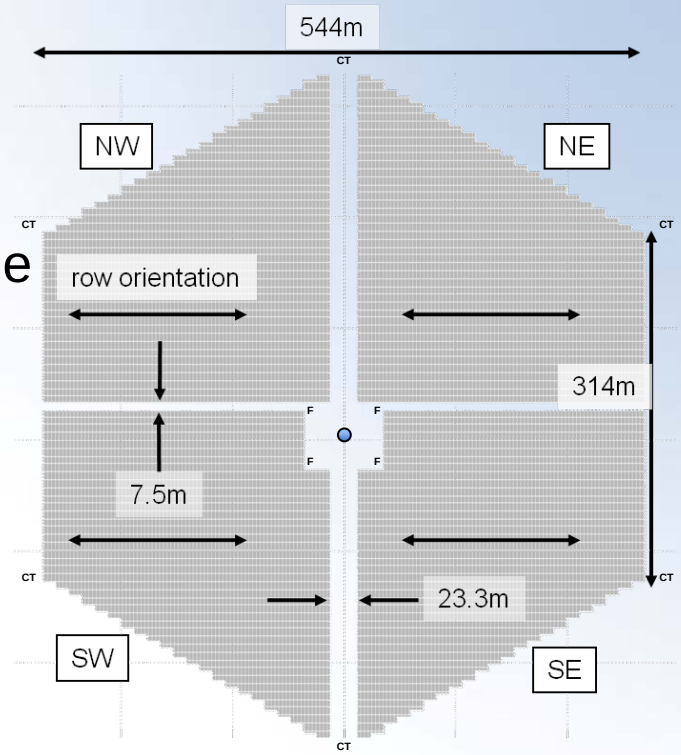
To:

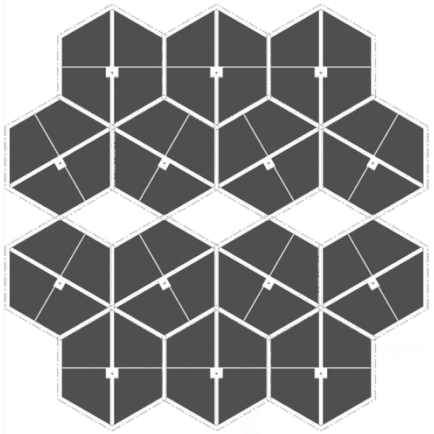
Next-generation SCS5 heliostats

B&W eSolar

Solar Collector System

- 14 hexagonal field modules
  - 92,000 1.1 m² SCS3 heliostats per module
  - 1.3 million heliostats total
  - Small north field bias
- SCS/SRS solar multiple: ~1.2





B&W 50-MW_t Molten Salt Receiver

- External, salt-in-tube configuration
  - Vertical tube panels, serpentine flow
  - Fully drainable (30s), fast startup capability
- Factory assembled, truck shippable for rapid field installation
- Leverages Solar Two and Sierra lessons learned

Geometrically similar Babcock & Wilcox 10-MW_t direct steam receiver in operation at eSolar's Sierra plant

B&W eSolar

Solar Receiver System

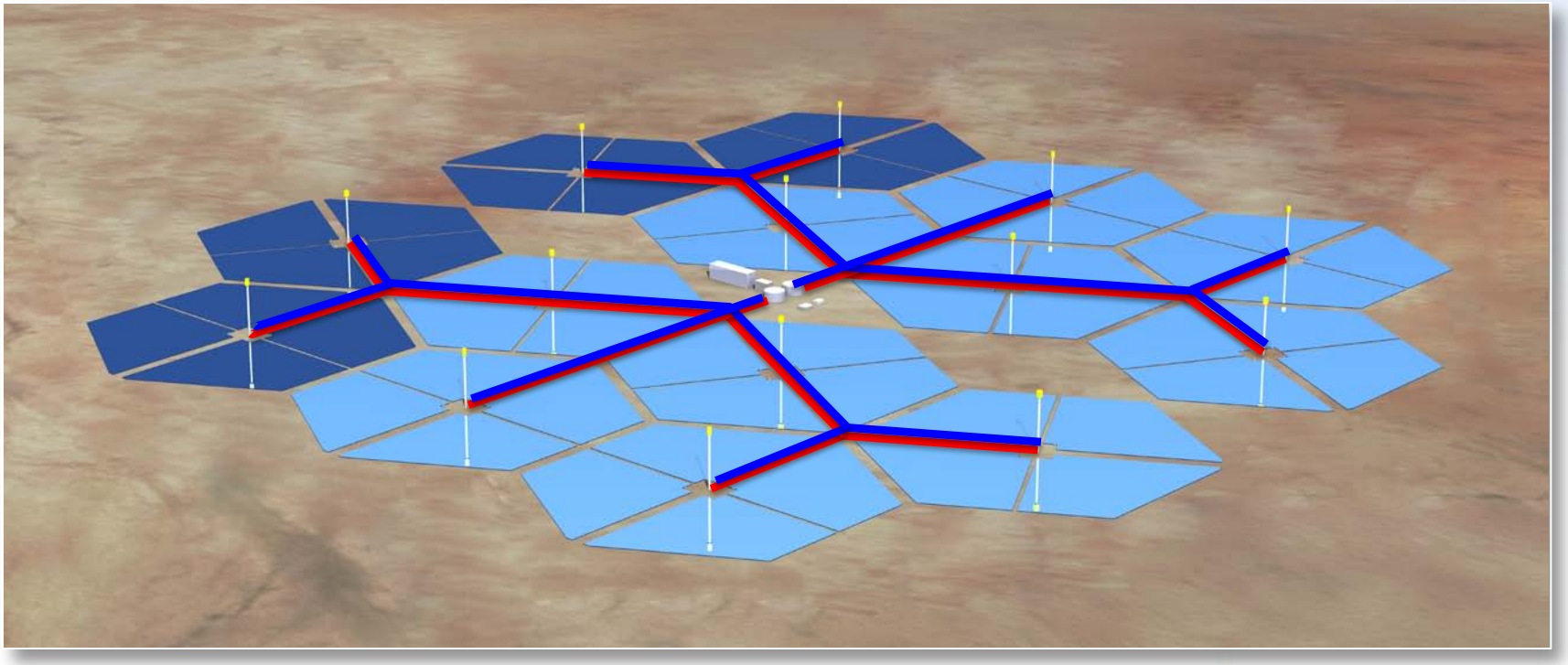
- 100-m tower
  - Wind turbine-type monopole, 5 sections
- Cold pumps
  - Three 50%, long-shafted, vertical turbine, suspended in tanks
- SRS/SGS solar multiple: ~2.5

B&W eSolar

DOE Baseload Configuration

Field Piping Details

- 10,500 m cold piping (carbon steel)
- 11,200 m hot piping (stainless steel)
- Heat traced, insulated, and drainable

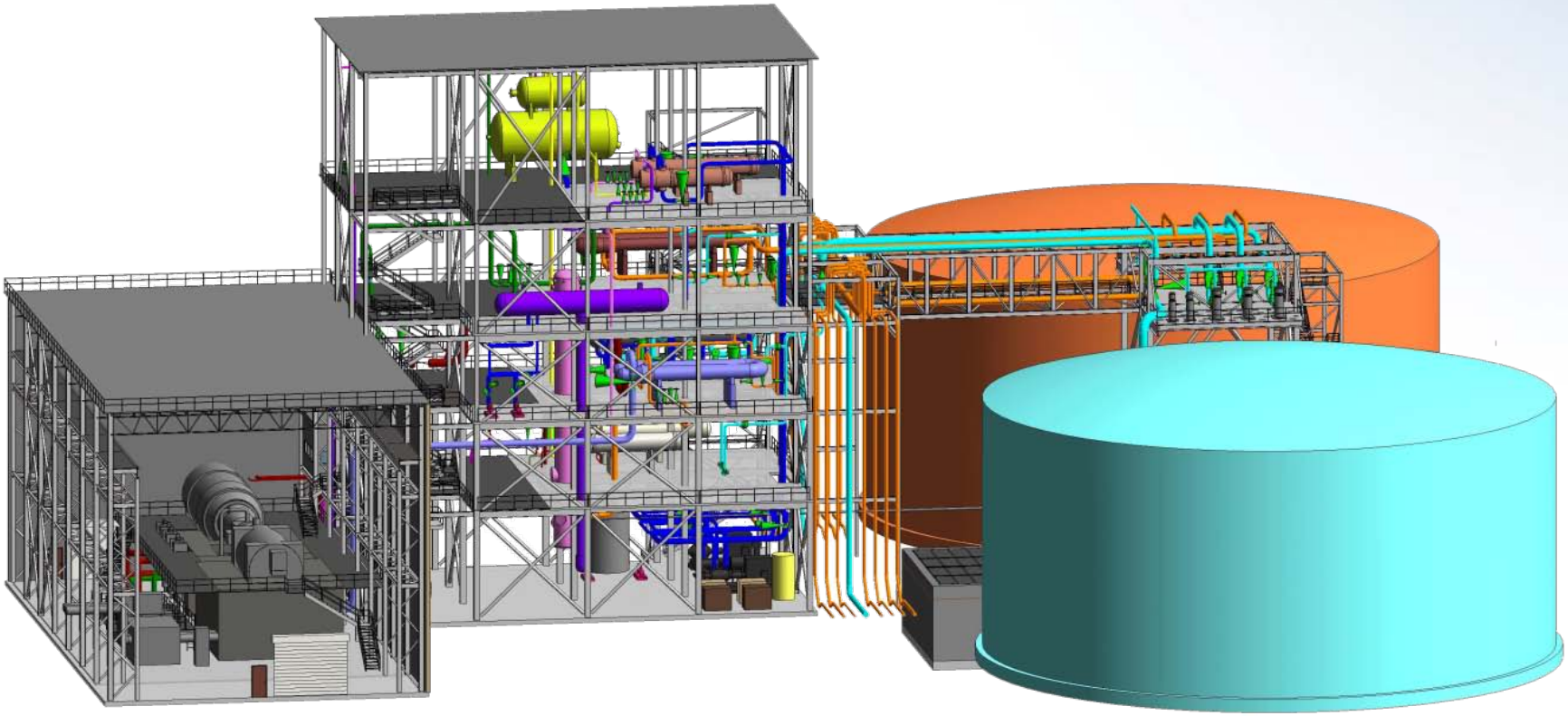


B&W eSolar

DOE Baseload Configuration

Power Block Systems

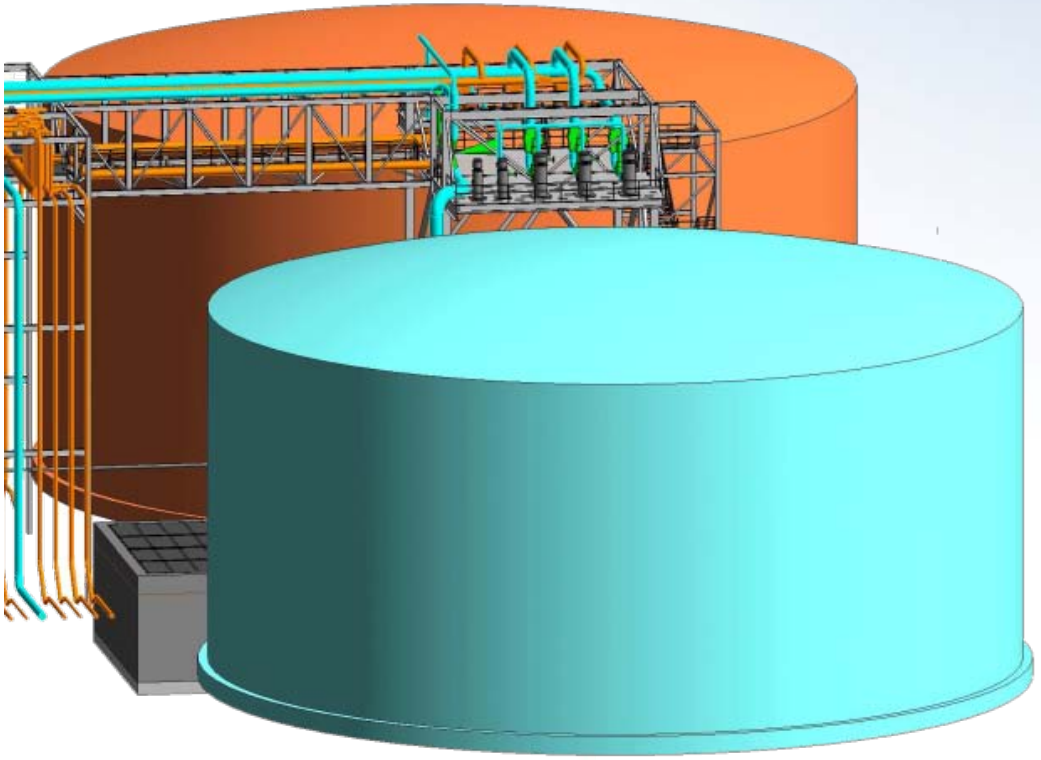
- Thermal storage system
- Steam generation system
- 100-MW steam turbine w/ reheat



DOE Baseload Configuration

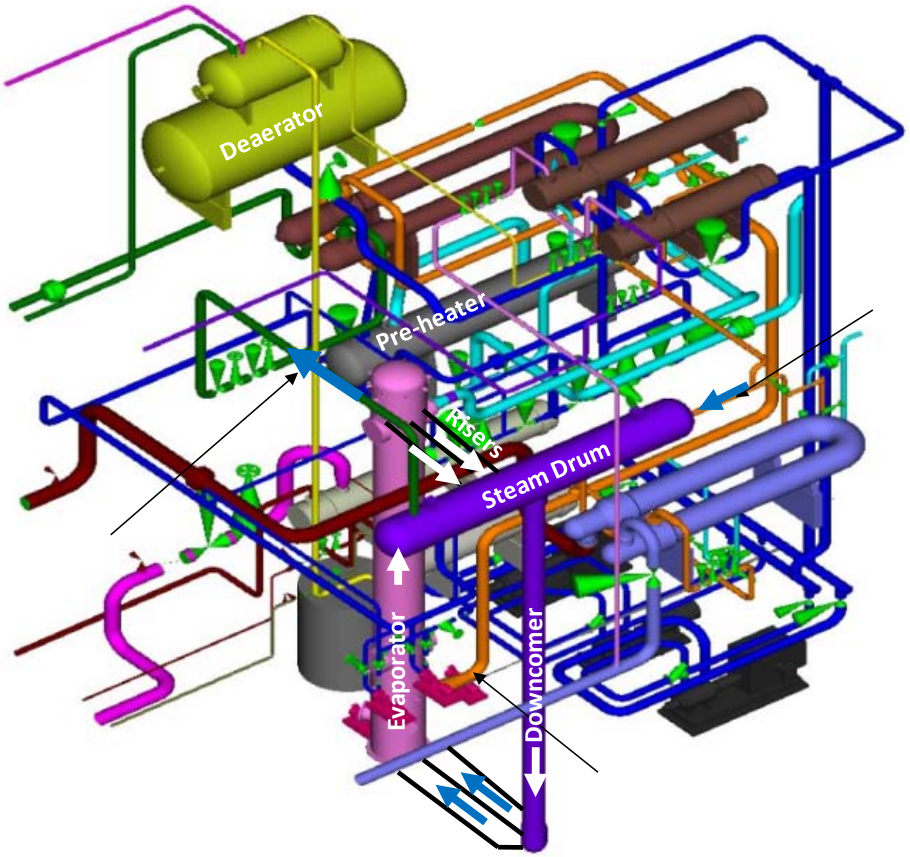
Thermal Storage System (TSS)

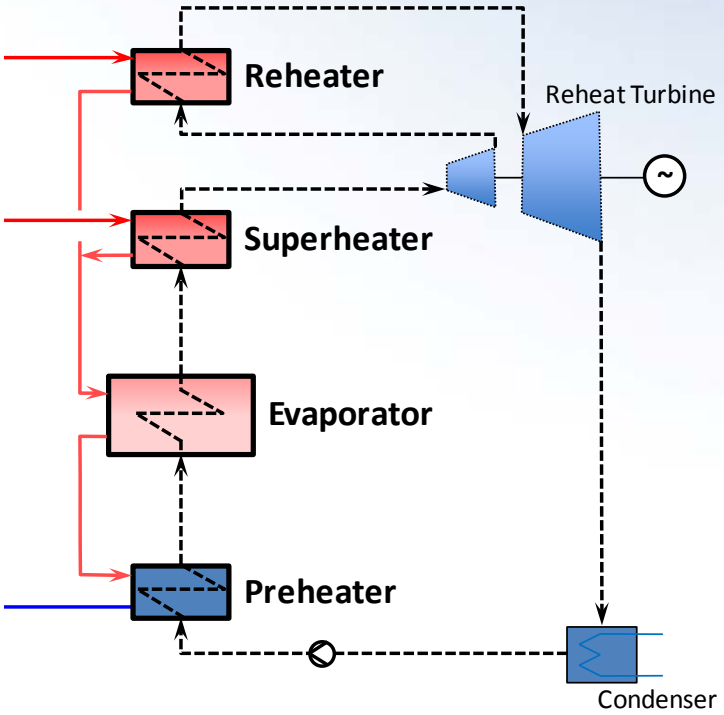
- Rated capacity
  - 3500 MWh_t (13.1 hours)
  - 36,500 metric tons of salt
- Hot and cold tanks
  - 39-m diameter
  - 17.5-m height



275-MW$_t$ Steam Generation System

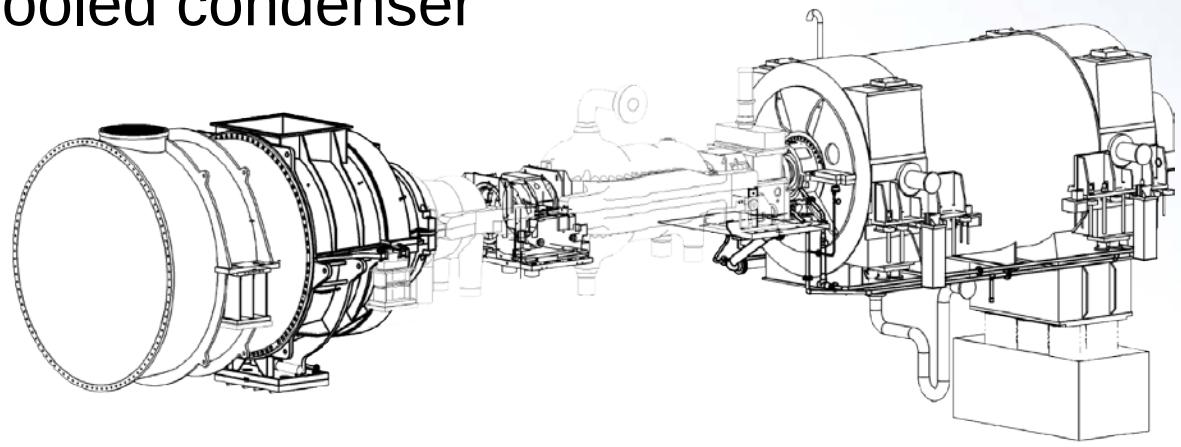
- Preheater, Evaporator, Superheater, & Reheater vessels
- Natural-circulation Evaporator design
- Detailed transient and dynamic analyses
- Leverages Solar Two lessons learned





Power Generation and Plant Controls

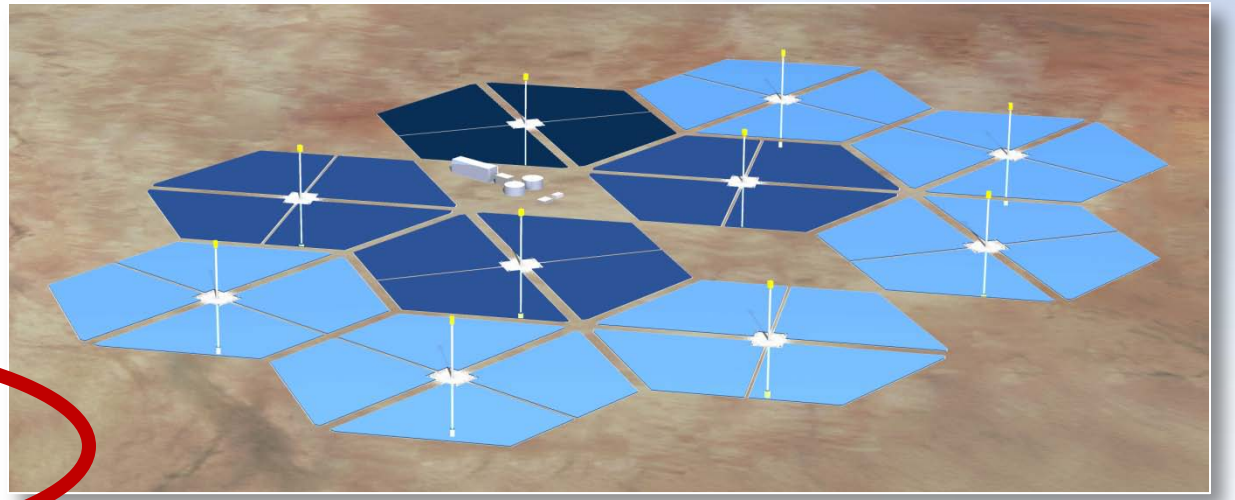
- Power generation system (PGS)
  - 100-MW Rankine-cycle reheat turbine generator
  - Gross thermal-to-electric efficiency: 42%
  - Air-cooled condenser



- Plant Control System (PCS)
  - Designed for automated operation
    - No manual control required for daily functions
  - Total IO count: ~8100

Alternative Configurations

- Single module (possible ISCC integration or demo)
- 4-modules
  - 50-MW, 40% capacity factor
  - 100-MW, 20% CF peaker
- 10-modules
  - 100-MW, 50% CF

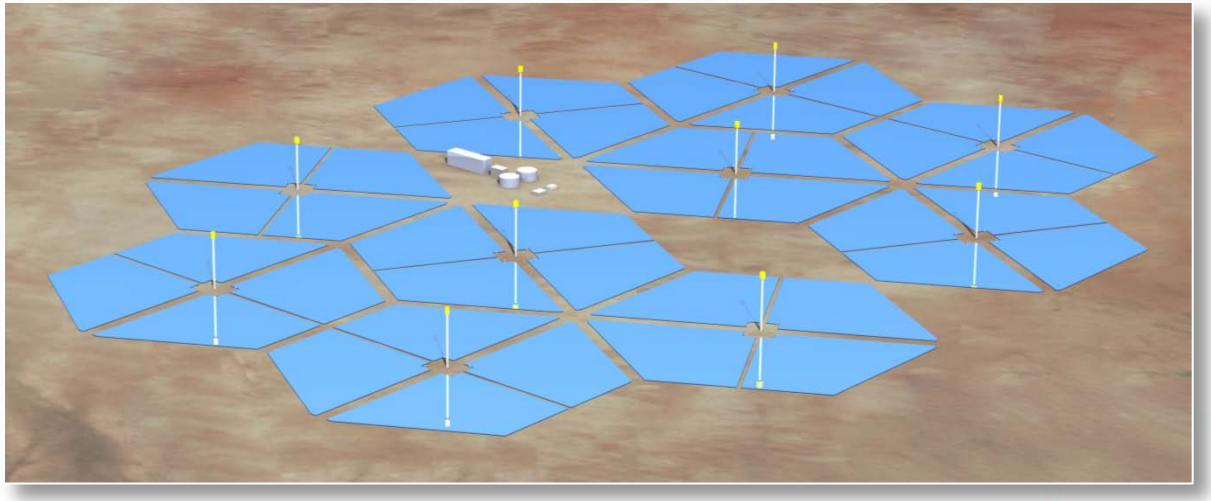


- All configurations utilize
  - Identical modules (heliostat field, receiver, tower)
  - Similar, scaled SGS and TSS components

B&W eSolar

Commercial System Configuration

- Plant rating **100 MW**
- Number of fields/towers **10 towers**
- Hours of storage **6 hours**
- Solar multiple **1.8**
- Capacity factor **50 %**
- Dry cooling, no hybridization



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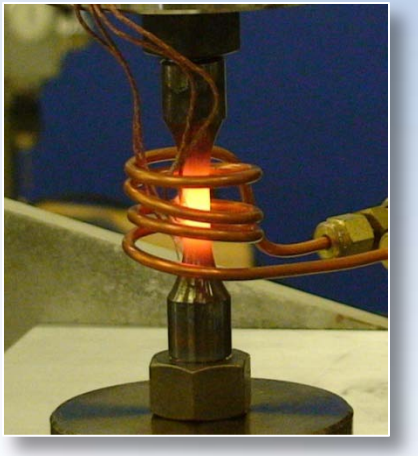
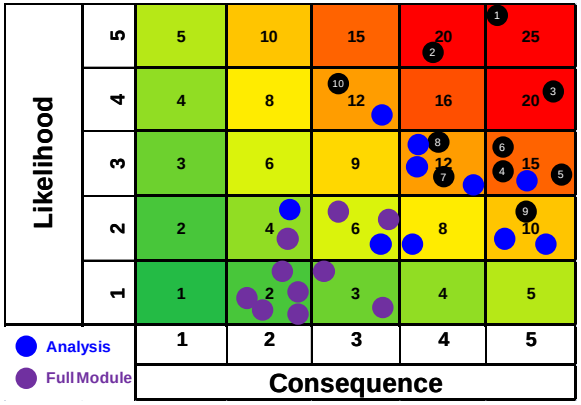
On-Going Work (Beyond DOE Contract)

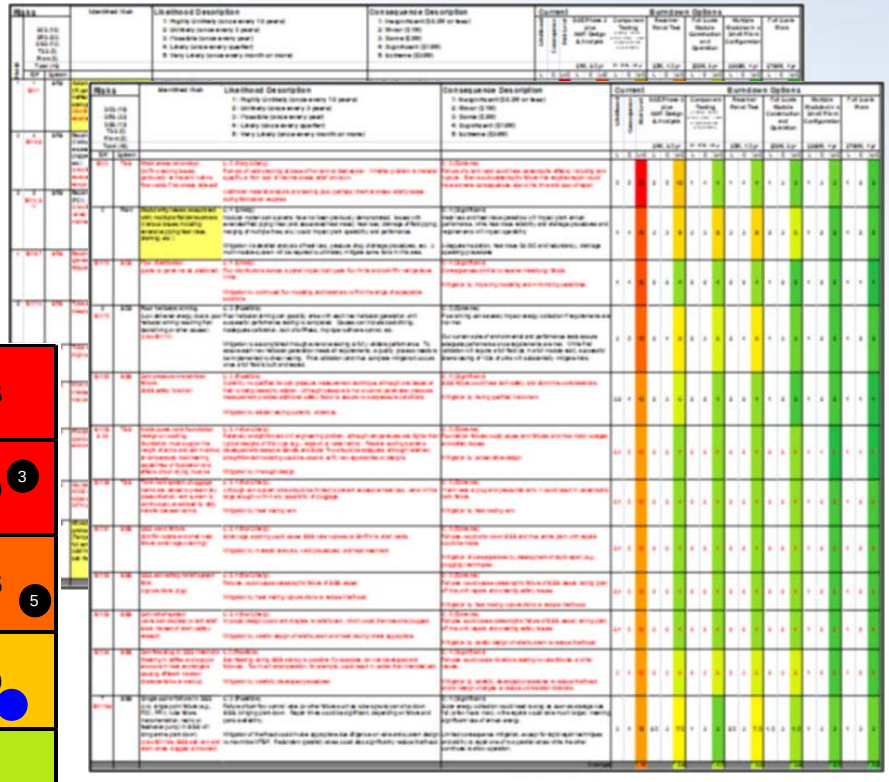
- Risk assessment and mitigation
- Receiver design refinement
- Materials testing
- Heliostat development
- Project development

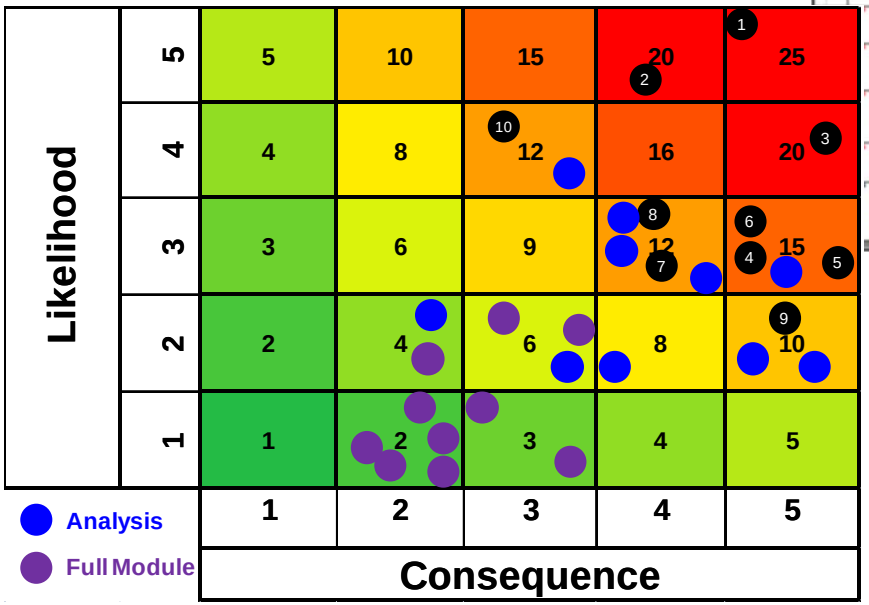




Risk Assessment and Mitigation

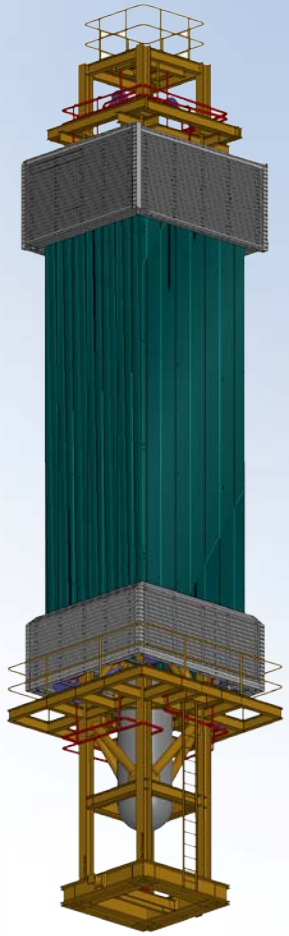
- Based on likelihood and consequences of various failure modes, top receiver risks and other risks identified and ranked
- Range of mitigation options considered
  - Additional design and analysis beyond DOE Phase 2
  - Component testing
  - Receiver panel test
  - Full-scale module test
  - Multi-module plant
  - Full-scale commercial plant

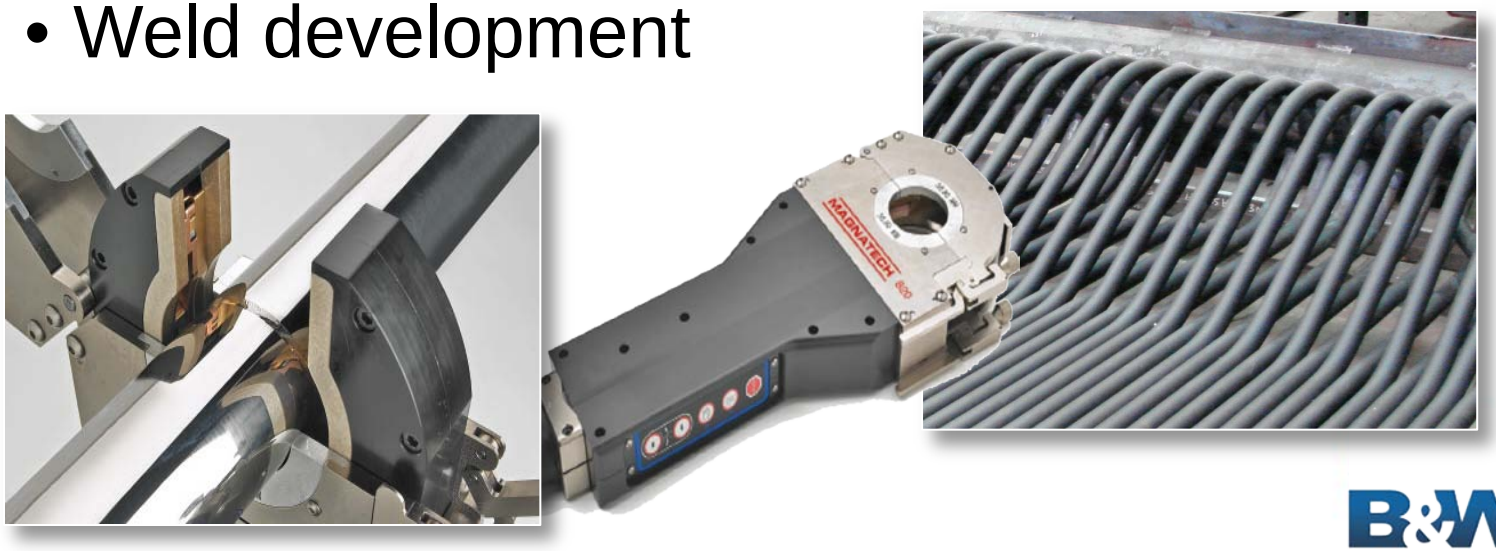




Receiver Design Refinement

- Dynamic modeling
- Transient stress analysis
- Tube-to-header design optimization
- Tube bend testing
- Tube panel optimization for weld access
- Electric heat trace system refinement
- Weld development





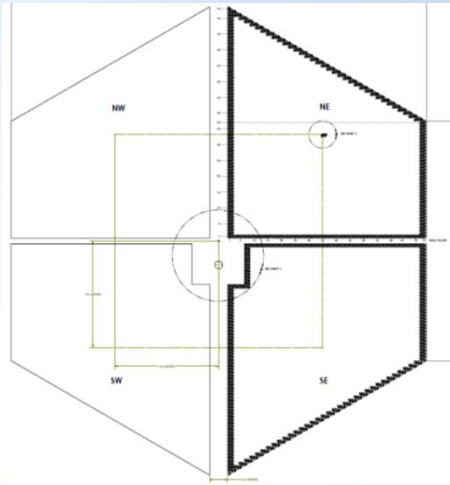
Materials Testing

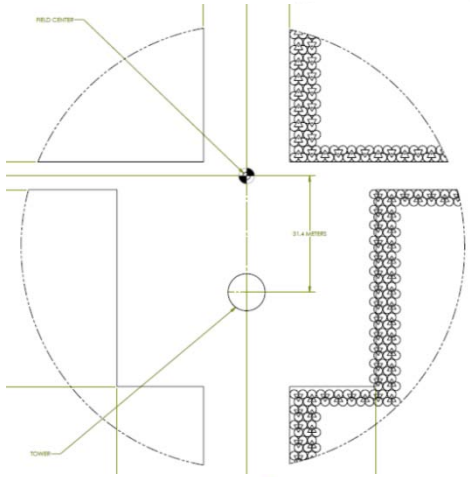
- Receiver material fatigue testing (ORNL & SNL)
  - Tube and bar stock materials
  - Isothermal and thermomechanical fatigue
  - w/ and w/o hold times and salt contact
- Corrosion testing
  - Electrochemical
  - Stress corrosion cracking
  - Salt immersion tests (SNL)
- Receiver tube paint testing
  - Adhesion
  - Aging (3000 hr)
  - Thermal Cycling

eSolar's New 2-m² SCS5 Heliostat

eSolar's New SCS5 Heliostat

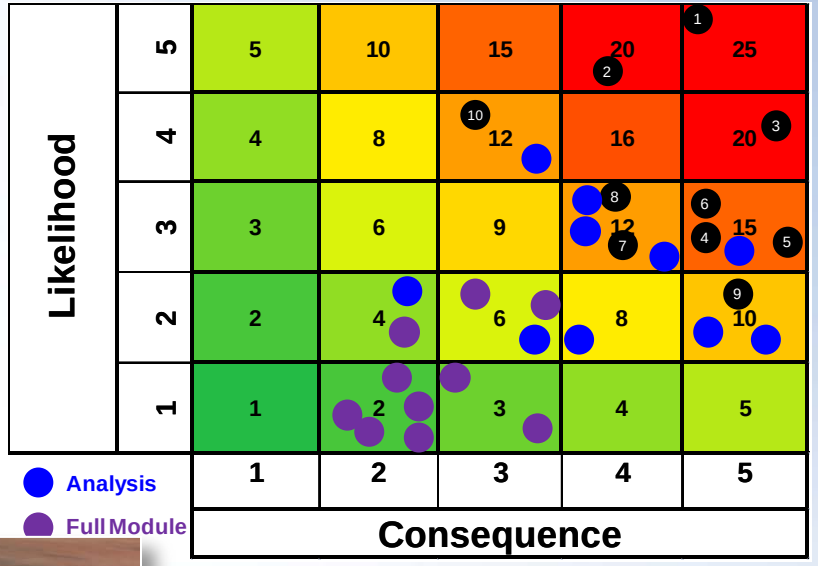
- SCS5 design optimized around molten salt module
  - Higher performance and reliability
  - Simplified electrical and networking systems
  - Parts count reduction and environmental sealing
  - Significantly reduced all-in cost
  - Utilizes eSolar's proven Spectra control system
- Heliostat field layout similar to SCS3 layout

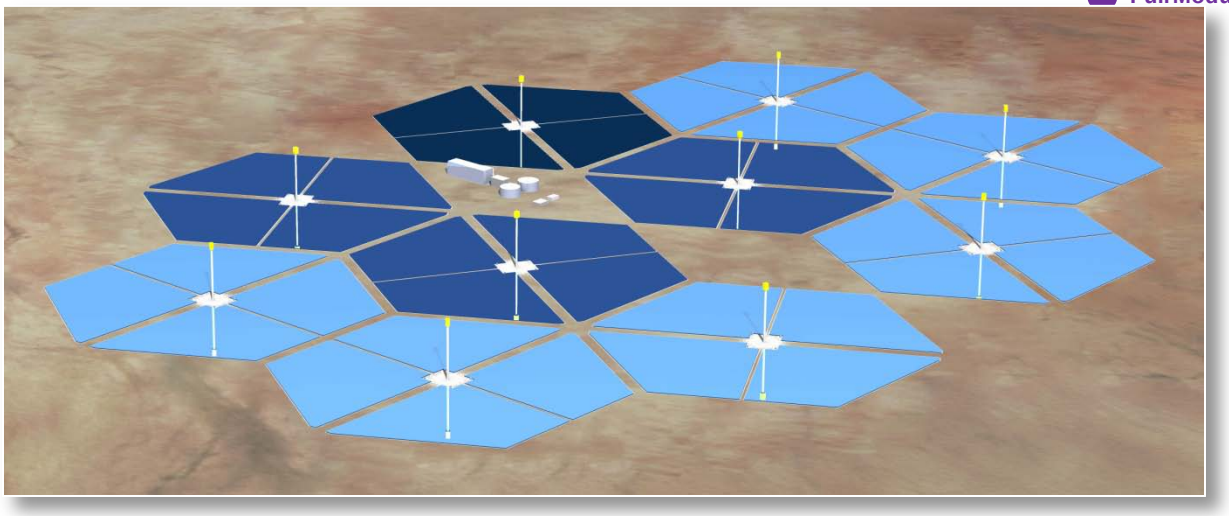




Next Steps

- Investigating
  - Project opportunities
  - First-of-a-kind build strategies





- Full-scale module
- Multi-module plant
- Full-scale commercial plant

- Prefer staged approach of an “Expandable Peaker”
  - Best of multi-module and full-scale plant options combined in a first plant

B&W eSolar

Our Vision:

Changing the world by making solar power competitive with fossil fuels

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