ABENGOA SOLAR

Solar Power for a Sustainable World

Thermal Energy Storage: Changing the Shape of Solar Integration

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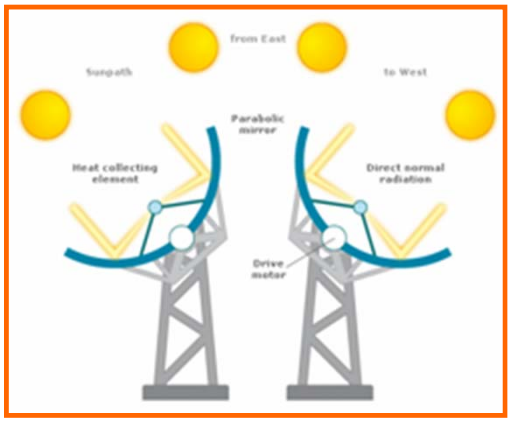
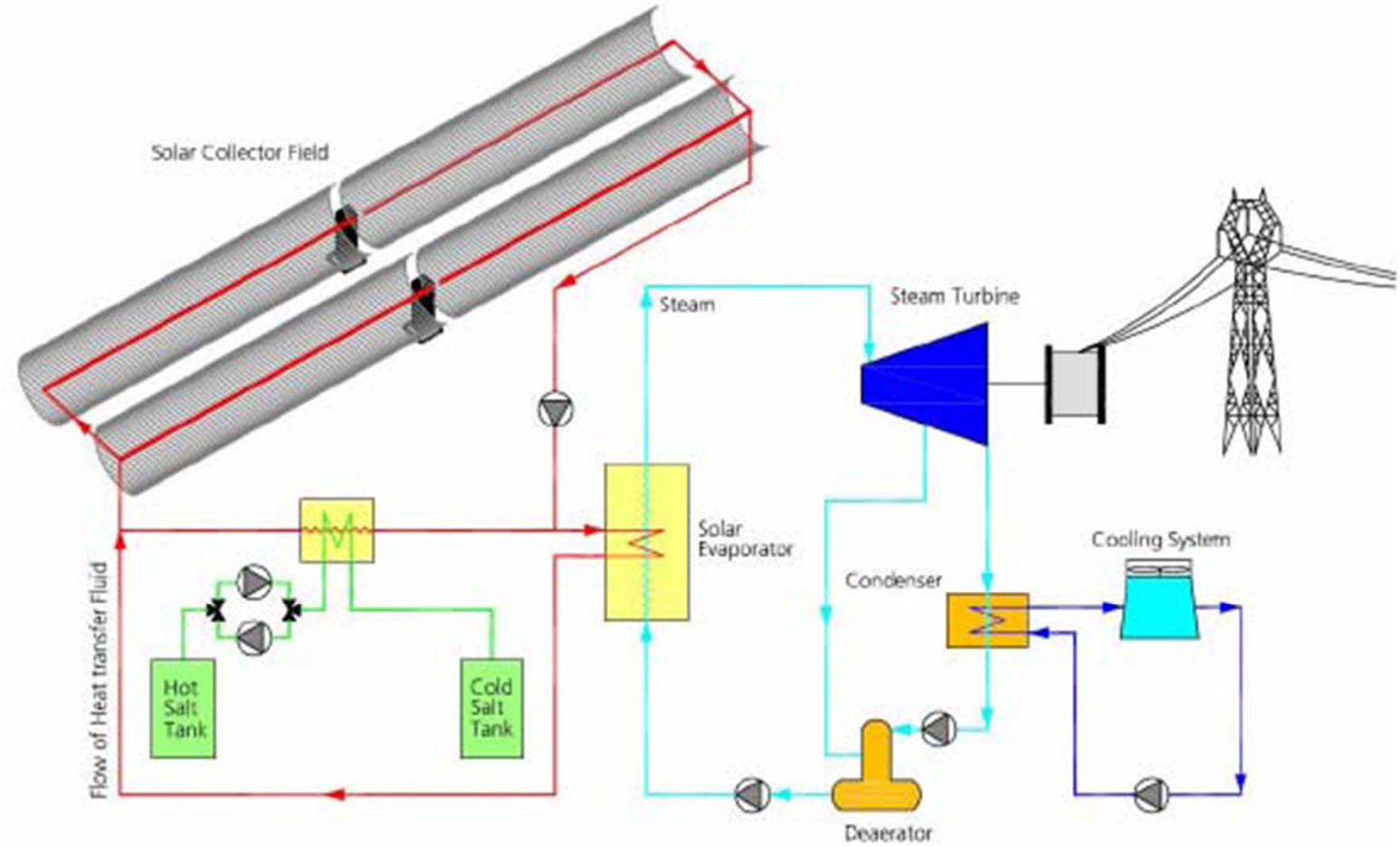
Concentrating Solar Power and Thermal Energy Storage

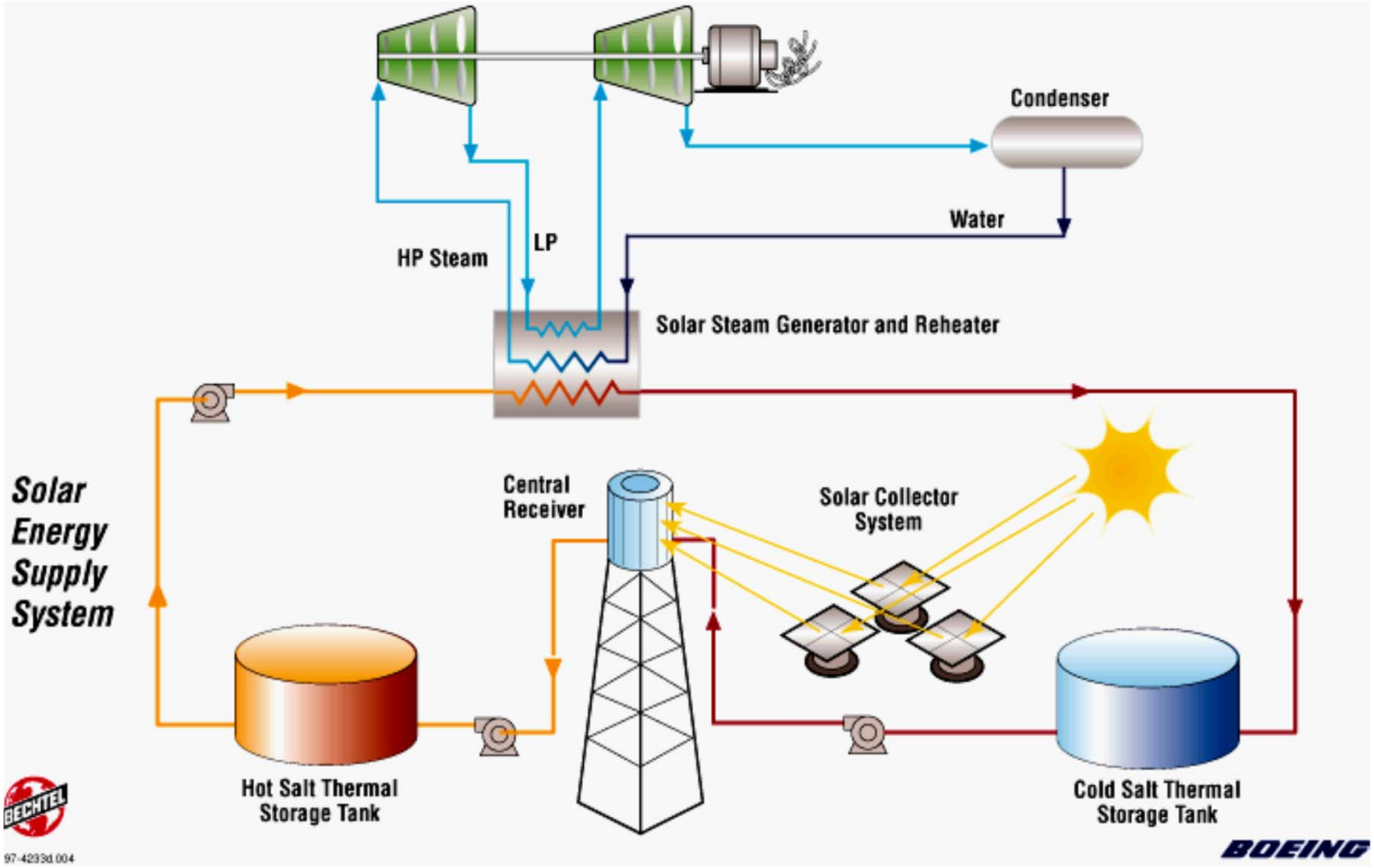
- Solar radiation strikes the earth with predictable intensity
- This energy can be collected with mirrors and focused/concentrated to heat a fluid
  - Trough plants
  - Central receiver plants (towers)
- Use the heated fluid to produce steam and run a steam turbine and generator
  - Standard steam power cycle (Rankine cycle)
- Can oversize the solar collector field to collect excess heat
  - Heat that is not immediately converted to steam for use in power cycle can be stored and converted to electricity later
- Thermal energy storage (TES) in CSP plants can:
  - Allow buffering during transient weather conditions
  - Increase solar plant capacity factors
  - Increase dispatchability of solar power



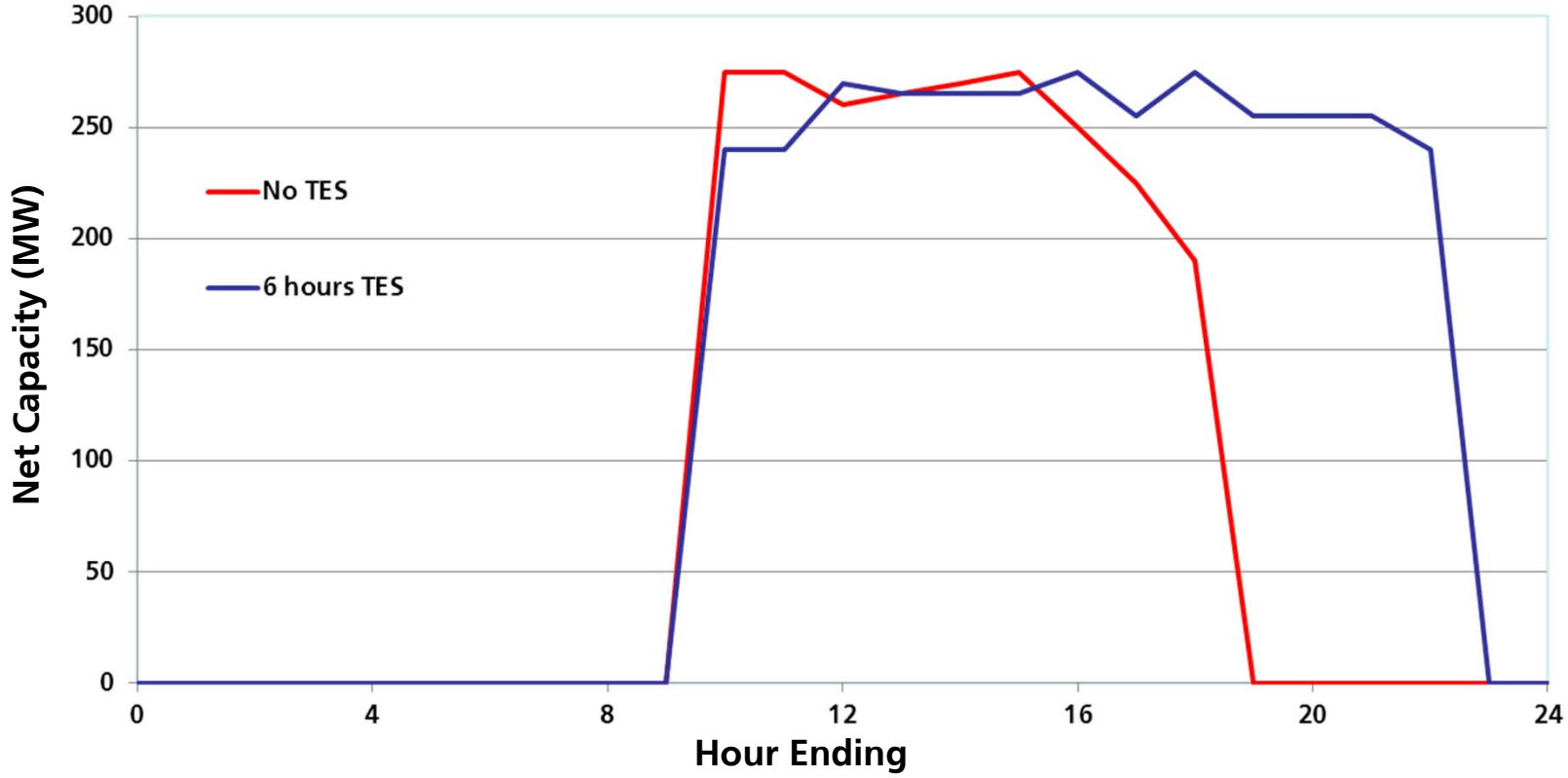
Parabolic Trough Process Flow Diagram with Indirect Thermal Energy Storage



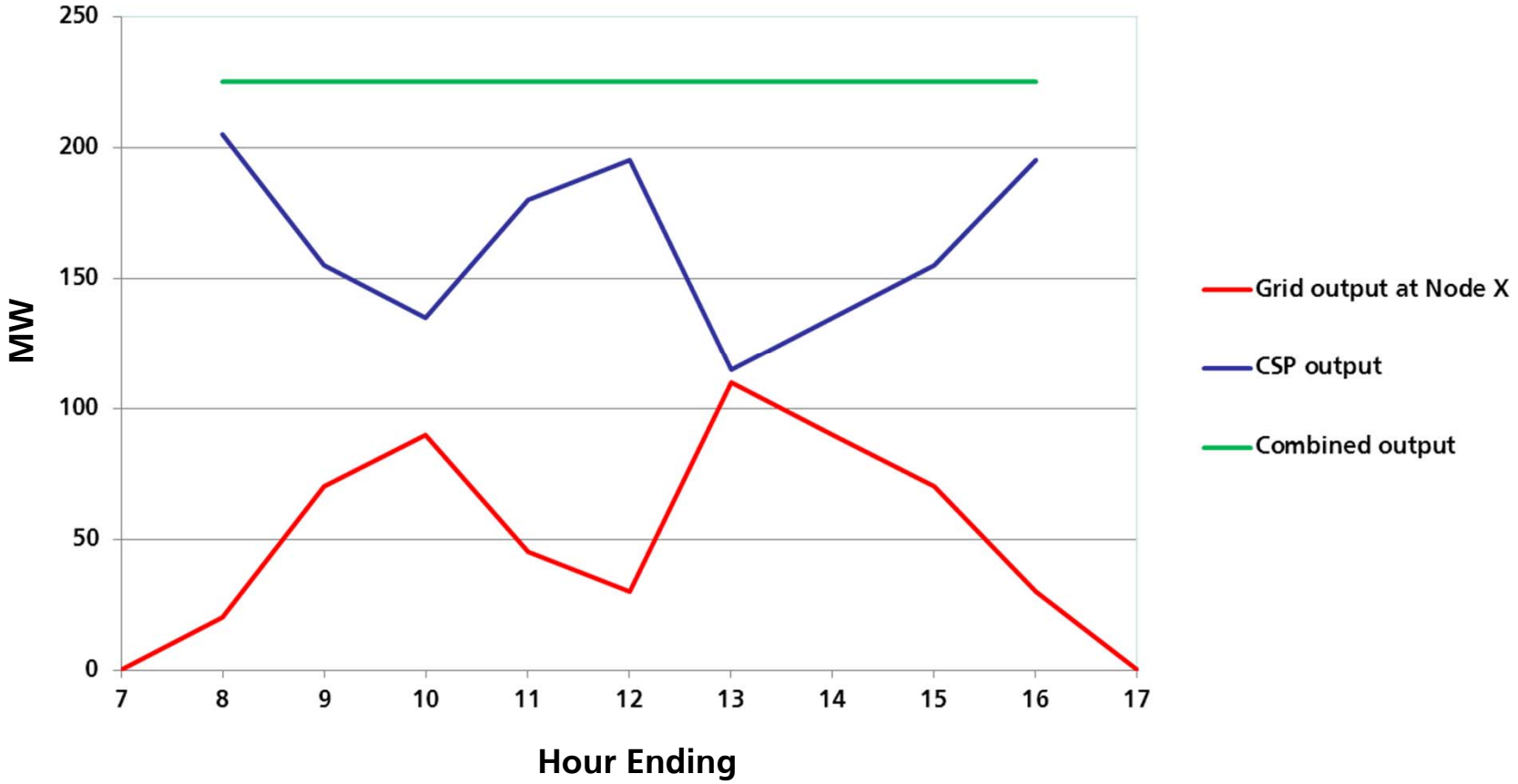
Tower Process Flow Diagram with Direct Thermal Energy Storage



Typical Summer Day Output
250 MW Trough Plant with & w/o TES



CSP Plant with TES Used to Level Output of Other Renewables



TES – Viable and Commercially Available

- **SEGS I – Daggett, CA**
  - 13.4 MW plant with 3 hours of mineral oil direct storage
  - Started up in 1984 and operated until 1999

- **Solar Two – Daggett, CA**
  - 10 MW plant with 3 hours of molten salt direct storage
  - Started up in 1995 and operated until 1999

- **Andasol I and II – Spain**
  - 50 MW plants with 7.5 hours of 2-tank, molten salt indirect storage
  - Started up in 2007 and 2008 and are operating commercially
- **Extresol I and II – Spain**
- **Gemasolar – Spain**
  - 17 MW central receiver tower w/ 17 hours of molten salt direct storage
  - Starting up in Spring 2011

- **Solana – Gila Bend, AZ**
  - 250 MW plant with 6 hours of 2-tank, molten salt indirect storage
  - Under construction

TES Economics

- **Solar thermal plants have high capital costs, but no fuel costs**
- **Levelized Cost of Electricity (LCOE):**

$$\frac{\text{Capital cost + O\&M costs}}{\text{Electricity produced over life of project}} \rightarrow \text{in \$/kW-hr}$$

- **TES adds to the capital cost, but does not necessarily increase the cost of energy**
  - For a trough plant utilizing indirect storage, TES will likely raise the LCOE
    - Upper temperature limit of HTF storage limits temperature of storage medium
    - Large volume (mass) of storage medium for a given amount of thermal storage
    - Capital cost associated with that TES system not necessarily offset by the additional MW-hrs produced over the life of the plant
  - For a central receiver plant utilizing direct storage, TES can decrease the LCOE
    - Storage medium can be raised to higher temperatures
    - Smaller volume for a given amount of thermal storage; more bang for the buck
    - Capital cost associated with this TES system can be offset by the additional MW-hrs produced over the life of the project

Policy Recommendations to Encourage TES in CA

The State of California can help foster TES implementation by creating a market, providing incentives, and lowering the cost of financing.

- Set targets for the procurement of thermal energy storage (AB 2514)
- Introduce time-of-day rules into the Renewable Portfolio Standard
- Add a "storage payment" on top of the MPR for solar thermal projects with storage
- California version of loan guarantee program
- Exemption of sales/use tax on energy storage components
  - Pass AB 1376 – partial sales tax exemption
  - Expand and pass AB 1057 (mfg sales tax exemption) to include thermal storage eqpt
- Support and lobby for federal funding programs
  - Extend Section 1603 Program (grants for energy property in lieu of tax credits)
  - Make permanent the 30% investment tax credit (will otherwise revert to 10% in 2017)
  - Make solar projects eligible for Private Activity Bonds