The Future of CSP: Dispatchable Solar Power

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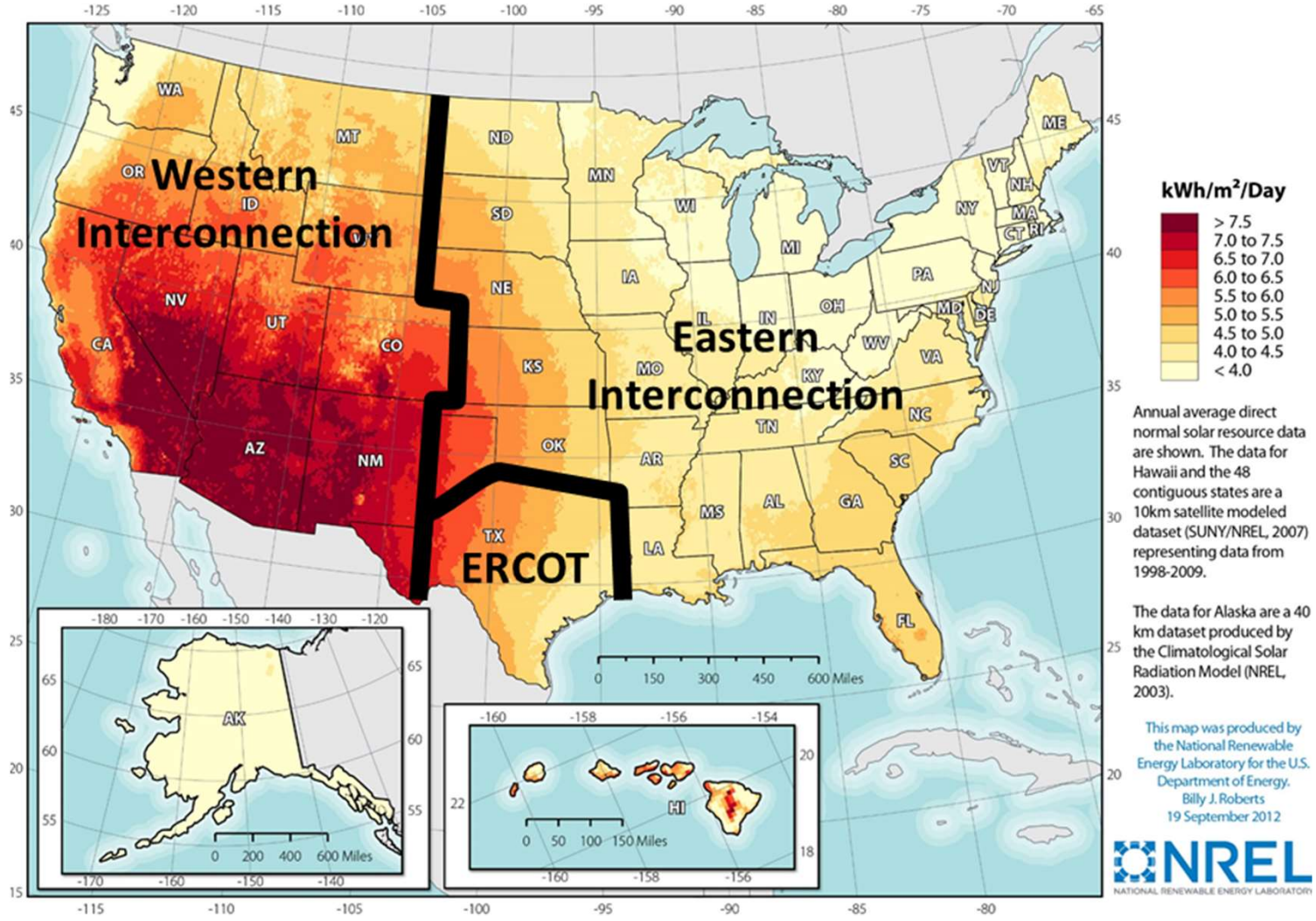
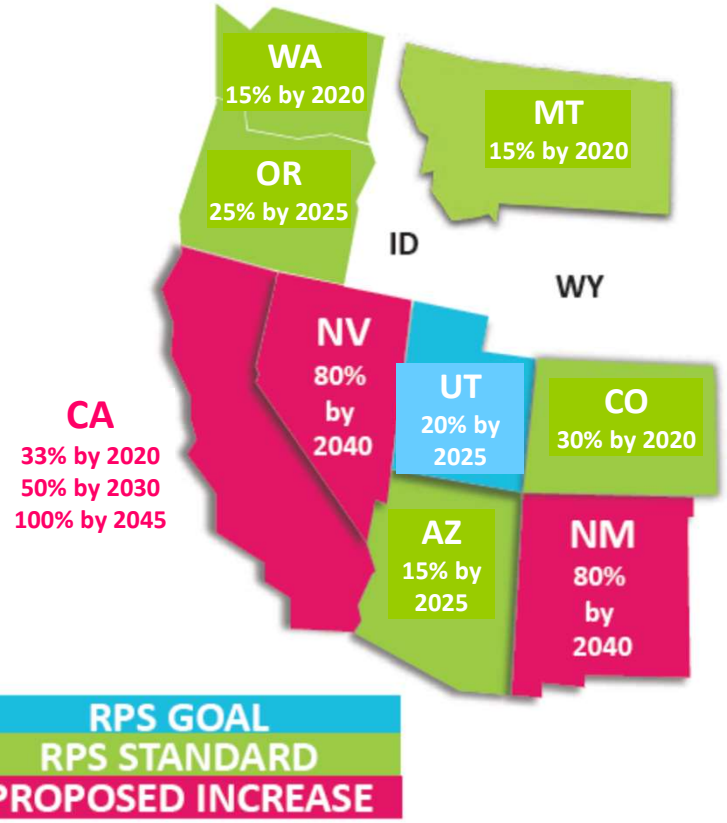
U.S. Direct Normal Resource Map & Transmission Interconnections



Decarbonizing the Power Sector

- Renewable deployment driven by both Federal and State policies.
  - Federal PTC & ITC drive economics
  - Federal PTC drives wind.
  - State policies and RPS mandates drive PV deployment
- Western states proposing more aggressive RPS targets
  - California **100%** by 2045
  - Nevada **80%** by 2040
  - New Mexico **80%** by 2040
- The Duck Curve problem occurs in 2020 when CA achieves 33% RPS.

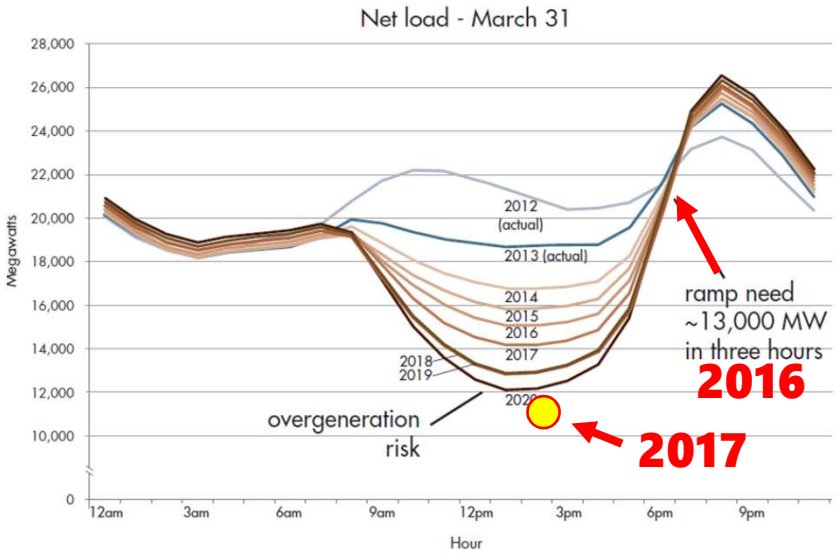
FIGURE ES-8. PROPOSED RENEWABLE PORTFOLIO STANDARD (RPS) INCREASES



Source: SNL – S&P Global Market Intelligence

Flexible Generation Needed

- The California “Duck Curve” is a sign of success in terms of achieving a meaningful contribution of renewable power on the grid.
- Managing the Duck is one of the key challenges to moving to higher renewable contributions on the grid.
- Utilities are responding by:
  - Closing baseload plants.
  - Adding flexible or “Peaking” natural gas resources.



CAISO Duck Curve

Can a dispatchable CSP plant fill the need for flexible peaking capacity?

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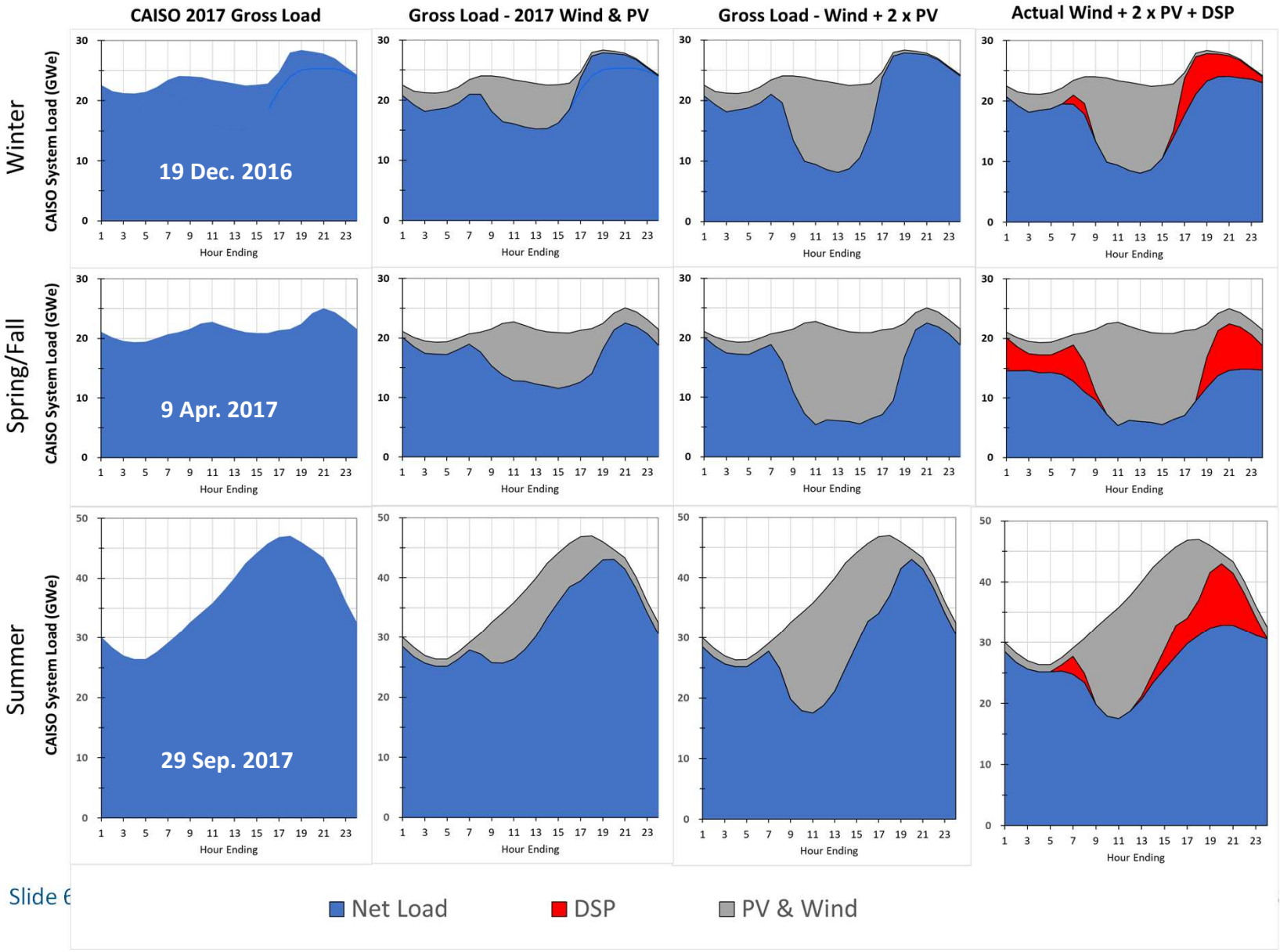
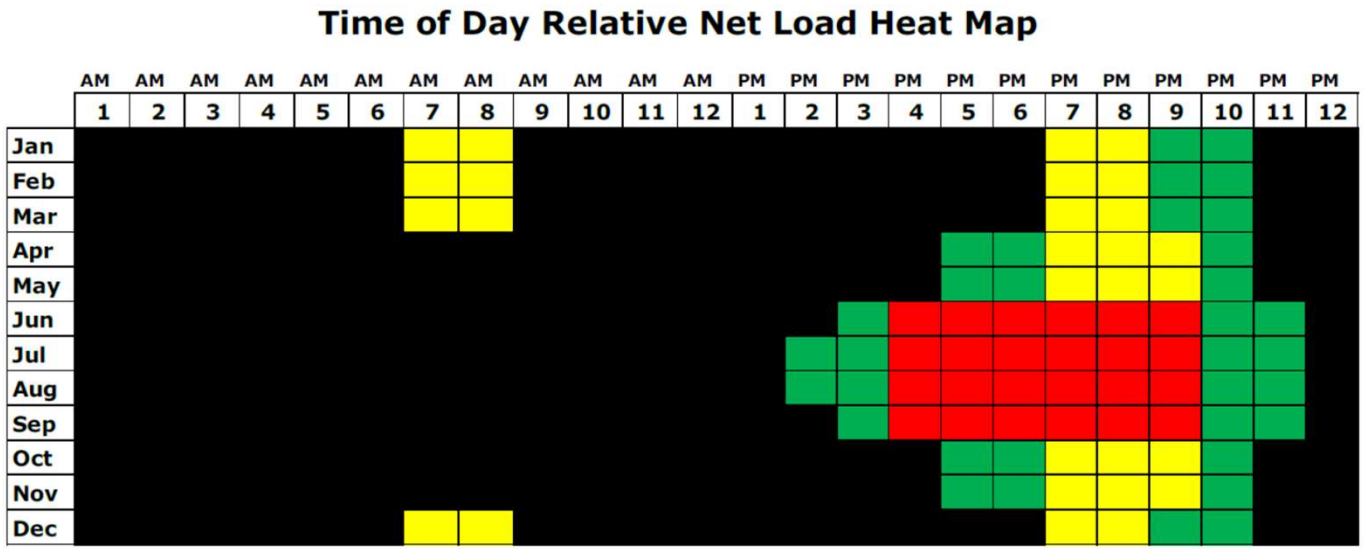
How can a dispatchable solar power plant help California?

Example based on Actual 2016/2017 CAISO System Load



Arizona Public Service (APS) 2017 Peaking Capacity RFP



Option 1: Time of Delivery Power Purchase Agreement

- Preferred = 3X Less Preferred
- More Preferred = 9x Less Preferred
- No power during "No Must Take Energy

Option 2: Thermal (Fossil) Tolling Power Purchase Agreement

- Capable of operating for **4 hours at 46°C** at 100% contract capacity.
- Dispatchable by APS with AGC (load following capability)
- Stable operation at a 25% loading.
- Capable of at least 2 starts per day.
- Faster starts and ramp rates are better

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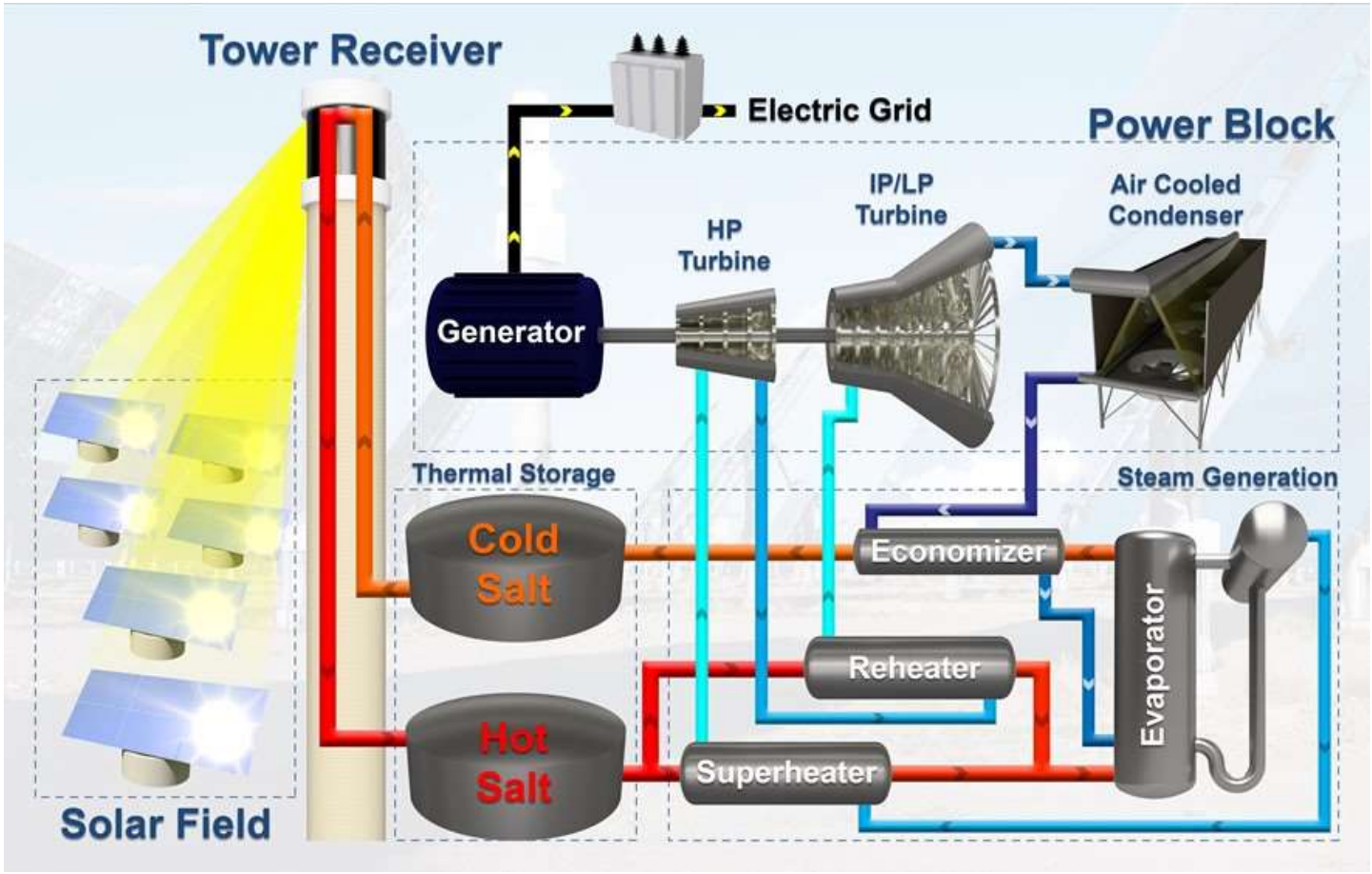
Dispatchable Solar Power (DSP) Plant

Uses Conventional Molten-Salt Tower Technology



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Dispatchable Solar Power Plant

- DSP Operational Requirements
  - Fast Starts & Ramps
  - Store solar energy during the day
  - Dispatch power anytime during next 24 hrs
- Cost Reduction
  - Standardized design
  - Power Parks
  - Compressed EPC schedule
- Commercialization
  - Conceptual engineering design and EPC cost estimate
  - Vendors identified for all key equipment
  - Address tower sensitive development issues
  - Outreach to Developers, EPCs, Utilities

Dispatchable Solar Power Plant Design

Configuration	Summer On-Peak 5 hours
Turbine Nominal Gross Power	**250 MW_e**
Turbine Nominal Net Power	**230 MW_e**
Power cycle gross thermal efficiency	44%
Power cycle cooling system	hybrid
Power cycle design ambient temperature	46°C
Solar Receiver design duty	**400 MW_t**
Solar Multiple	**0.65**
Tower Optical Height	170 m
Total Heliostat Area	**700,000 m^2**
Solar Field Area	256 ha
Storage Capacity	3,000 MWh_e
Storage Capacity	**5 hr**
Annual Gross Capacity Factor	**16.5%**
1st year Net Generation	**334.2 GWh_e**

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Fast Start Power Cycle

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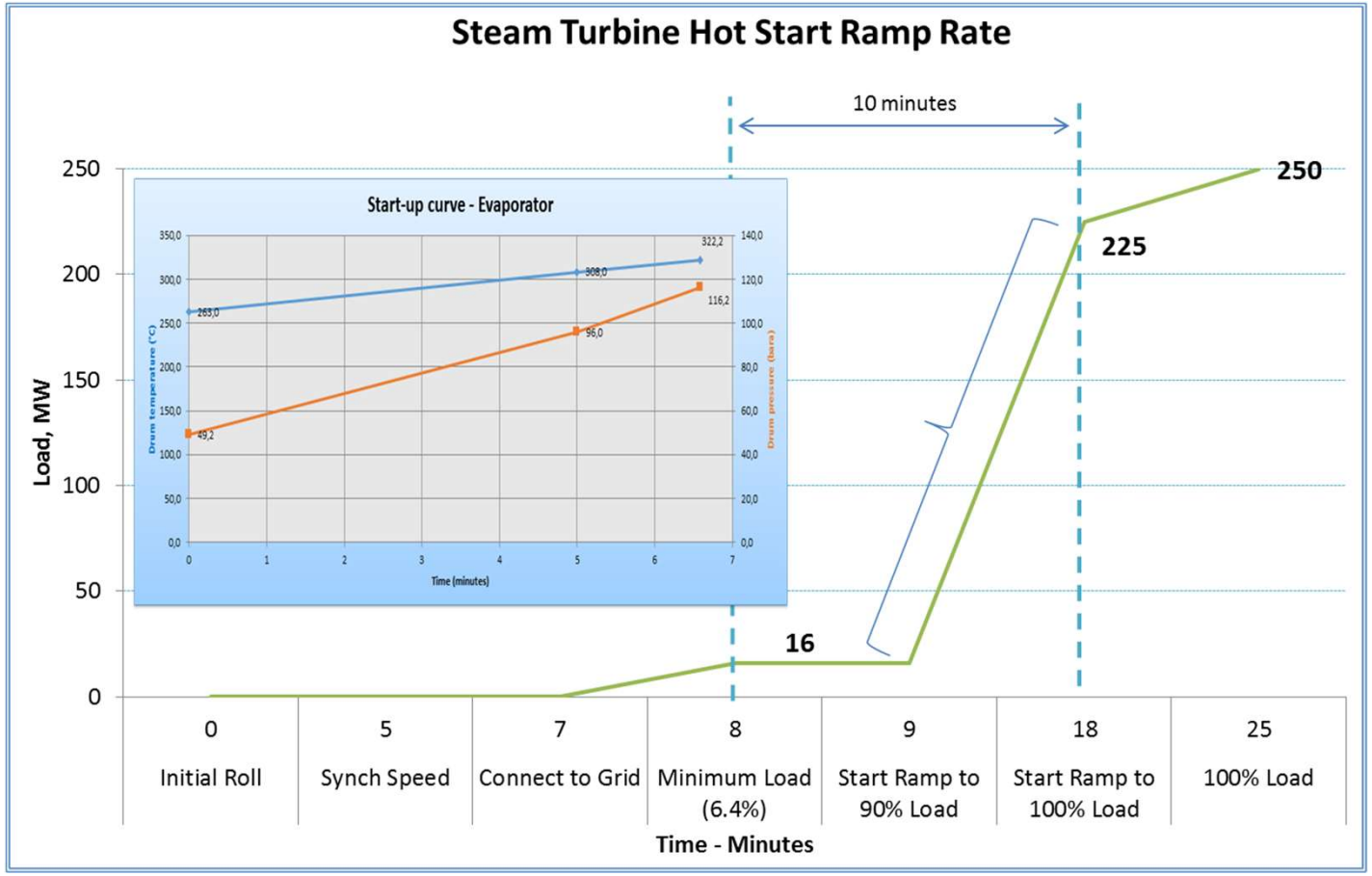
New Siemens SST900 Fast Start Steam Turbine +
Aalborg Molten-Salt Header Style Steam Generator



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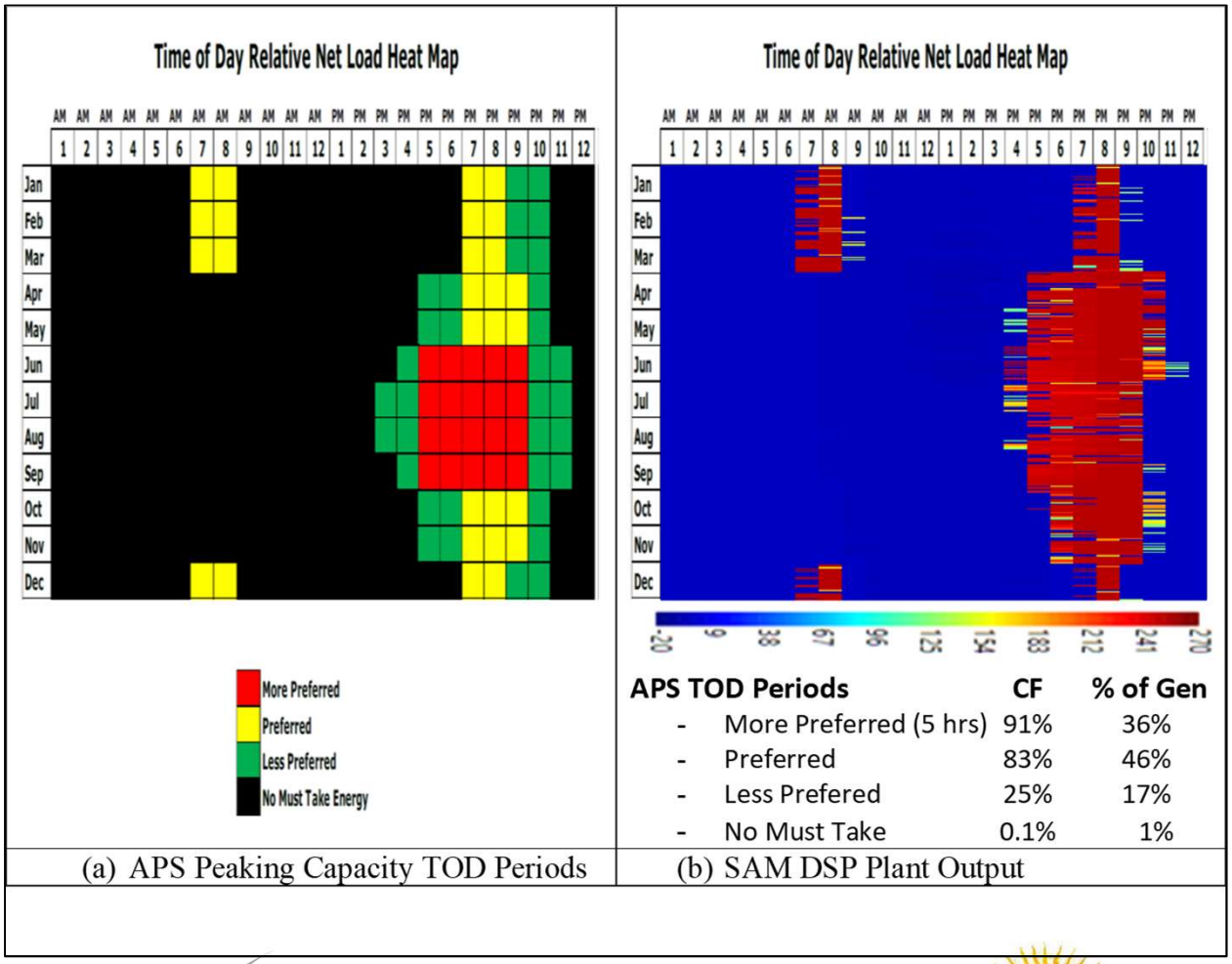
APS 2017 Peaking RFP TOD Periods and SAM Optimized DSP Dispatch Model



(a) APS Peaking Capacity TOD Periods

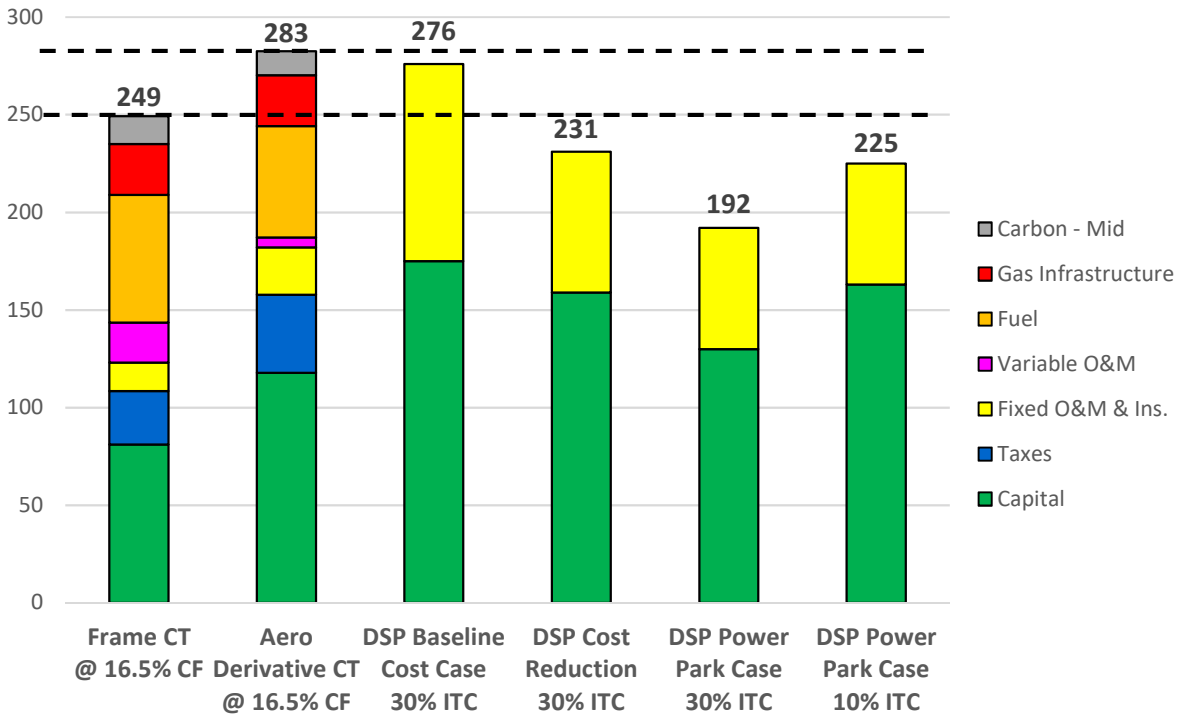
(b) SAM DSP Plant Output

This shows the modeled output of a DSP plant optimized for a specific TOD schedule requested by Arizona Public Service (APS).

- The plant achieves very high capacity factors during the more preferred and preferred TOD periods.
- Approximately 82% of the total energy from the plant is delivered during these periods.

DSP Plant vs. Combustion Turbine in Arizona

All-In Capacity Cost [$/kW-yr]



Summary

- Markets of the future need flexible renewable peaking capacity.
- Molten-salt tower technology can be used to be “dispatchable solar power” plants.
  - A reliable source of capacity
  - Can operate in flexible manner as a peaker
  - Can compete with new fossil plants in good resource locations.
- Different regions will have different needs.
  - Peaker CSP plants may make sense in some regions
  - Baseload CSP plants will continue to make sense in other regions.
  - Some regions could need both.

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Thank you for your attention!

Questions?

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