SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

PORTFOLIO REVIEW
2018

SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

Dispatchable Solar Power

Adapting CSTP to modern grid needs

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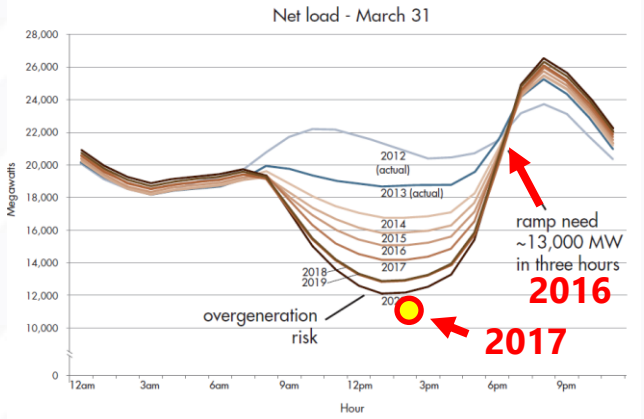
Solar Dynamics LLC

Flexible Generation Needed

- The CAISO “Duck Curve” is a sign of success.
- Managing the Duck is one of the key challenges to moving to higher renewable contributions on the grid.
- Utilities are responding by:
  - Reducing procurement of utility scale solar.
  - Closing baseload plants.
  - Adding flexible or “Peaking” natural gas resources.
- Western states proposing more aggressive RPS targets
  - California 100% by 2045
  - Nevada 80% by 2040
  - New Mexico 80% by 2040



CAISO Duck Curve

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

How can a dispatchable solar power plant help California?

Example based on Actual 2016/2017 CAISO System Load

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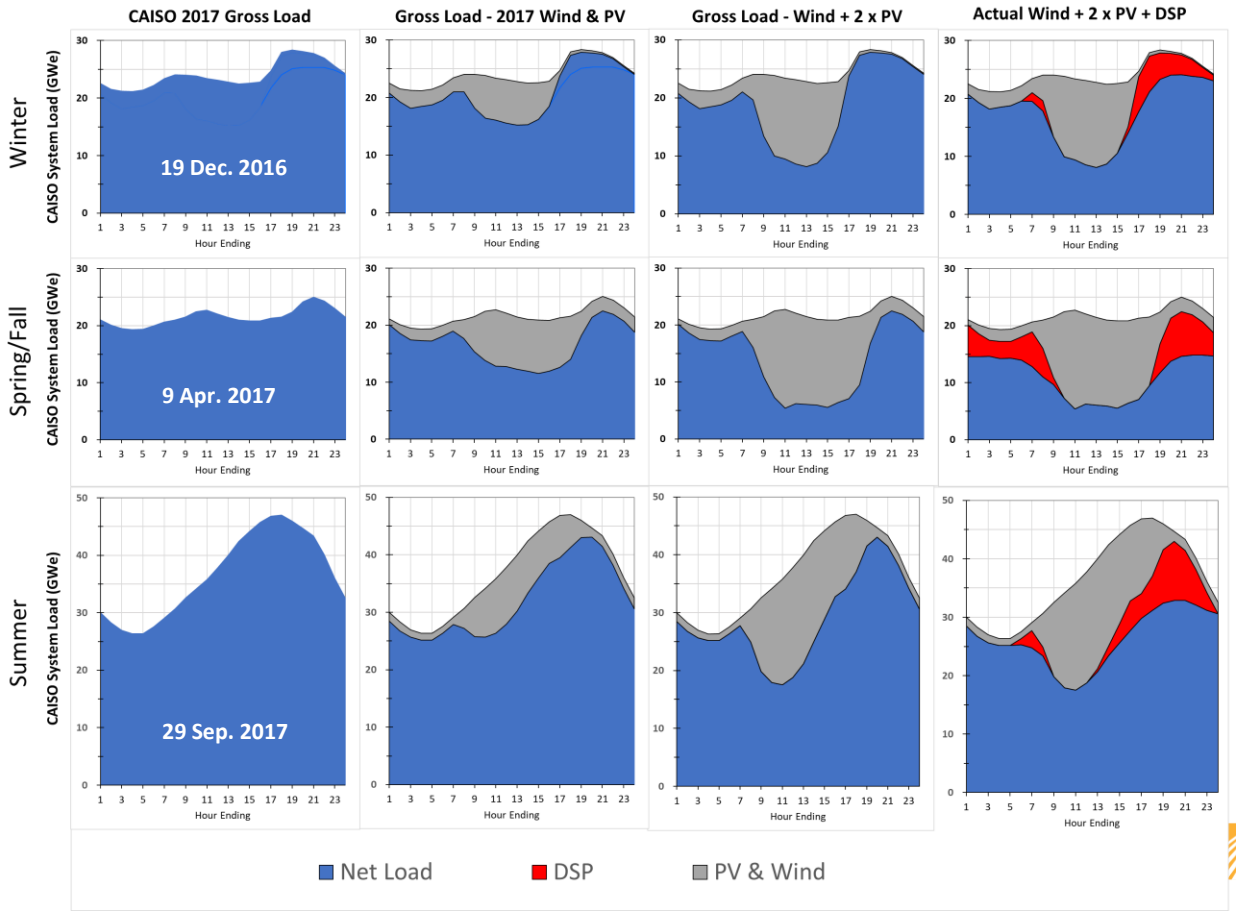

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Technology 2 Market: Dispatchable Solar Power Plant

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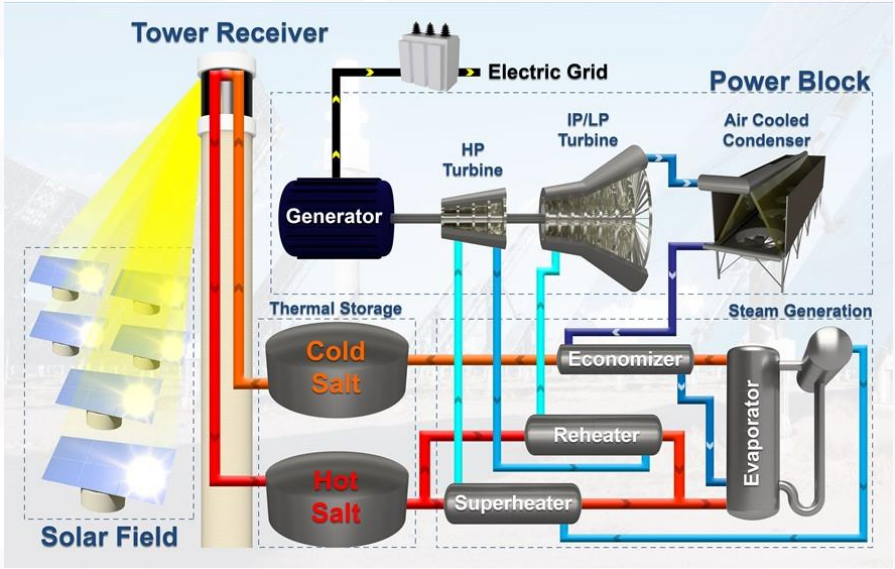
- Market Assessment
- DSP Operational Requirements
  - Fast Starts & Ramps
  - Store solar energy during the day
  - Dispatch power anytime during next 24 hrs
- Cost Reduction
  - Standardized design
  - Power Parks
  - Compressed EPC schedule
- Commercialization
  - Conceptual engineering design and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

Dispatchable Solar Power (DSP) Plant

Uses Conventional Molten-Salt Tower Technology



Sargent & Lundy

Morse Associates

BlüNebü

K&A

NREL NATIONAL RENEWABLE ENERGY LABORATORY

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Arizona Public Service 2017 Peaking Capacity RFP

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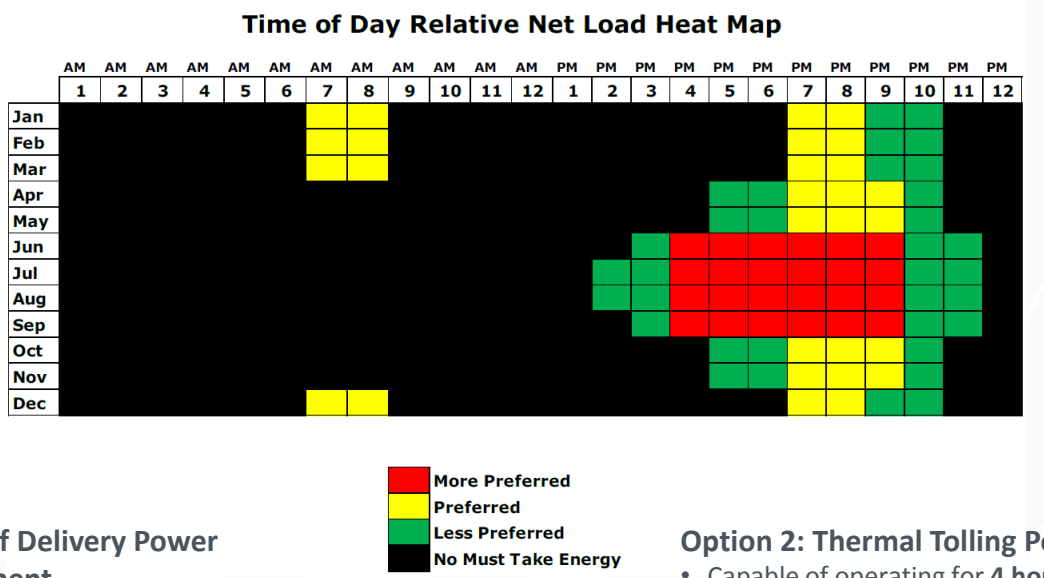

Option 1: Time of Delivery Power Purchase Agreement

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

Option 2: Thermal 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

Dispatchable Solar Power Plant Design

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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

Fast Start Power Cycle

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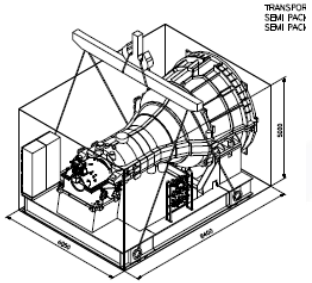
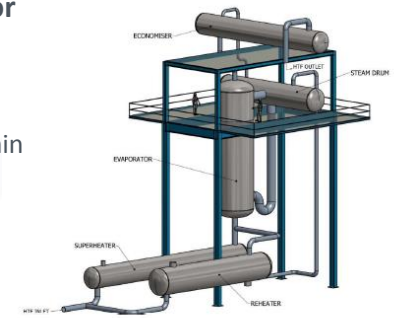
- **Siemens SST900 Steam Turbine**
  - Up to 250 MW
  - Fast Start & Ramp
  - Automated Start-up
  - Ships in 3 pieces
  - 30 years with daily starts

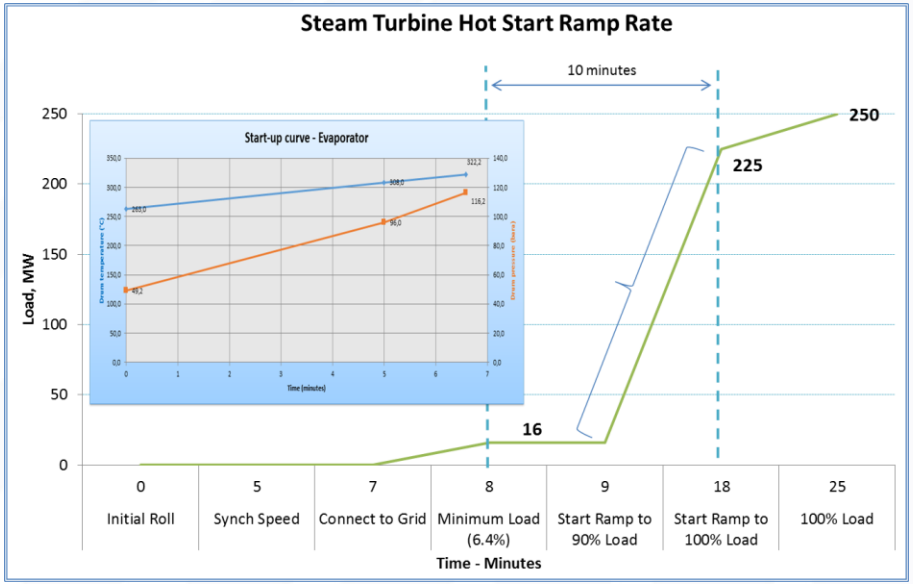


- **Aalborg Steam Generator**
  - Header Coil HX
  - Allows 5x temperature gradients
  - Starts up in under 10 min
  - Modular design
  - Passive circulation
  - Salt drains back.



AALBORG CSP - Changing Energy

Typical steam generator layout with Natural circulation is shown above. Two units are required for 50 MWe.



DSP Plant Output for APS TOD Schedule

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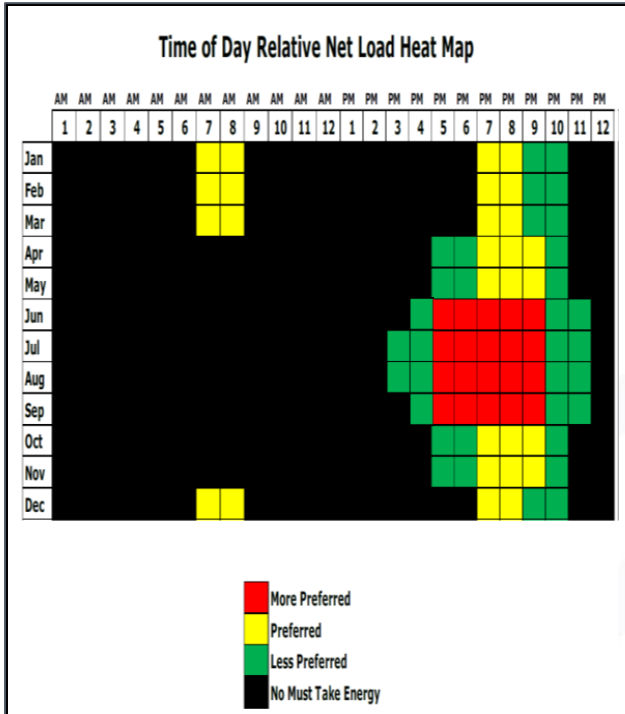
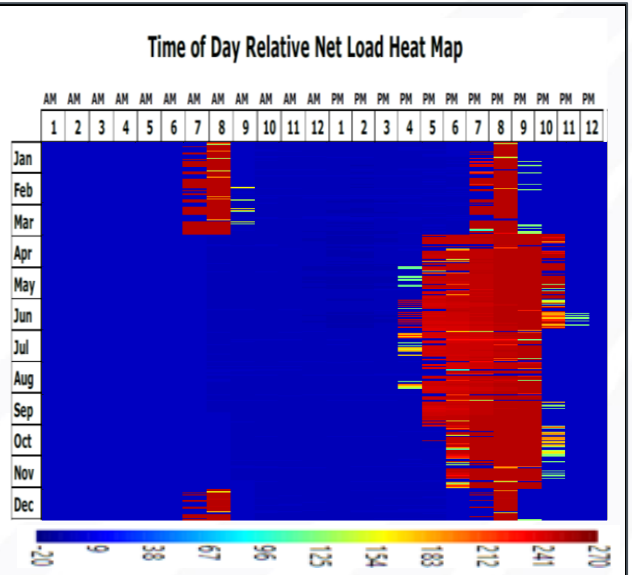


(a) APS Peaking Capacity TOD Periods



APS TOD Periods	CF	% of Gen
- More Preferred (5 hrs)	91%	36%
- Preferred	83%	46%
- Less Prefered	25%	17%
- No Must Take	0.1%	1%

(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.

Design Enhancements to Facilitate Permitting

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- **Site Selection**
  - Selecting a site with low permitting and development costs.
  - Build on previously disturbed private land.
- **Square Mile Site**
  - Infrastructure often set on section lines (roads, utilities, drainage)
  - More sites available to choose from.
- **Reduce Avian Impacts**
  - Reduce high flux standby zones
  - Minimize onsite habitat for animals and birds, reduce perching locations
  - Reduce bird “impacts” on heliostats and other structures
- **Minimize Visual Impacts**
  - Location away from population centers and airports.
  - Reduce brightness of spilled light on the tower, improved heliostat optics to reduce beam spillage, dark tower.
  - Aesthetically pleasing design
- **Reduced Water Consumption**
  - Dry or hybrid cooling,
  - Dry or reduced water cleaning of heliostats, ground cover
  - Improved water treatment, sCO2 power cycle

Square Mile Site

Visual Impacts

Avian Concerns

DSP Plant vs. Combustion Turbine in Arizona

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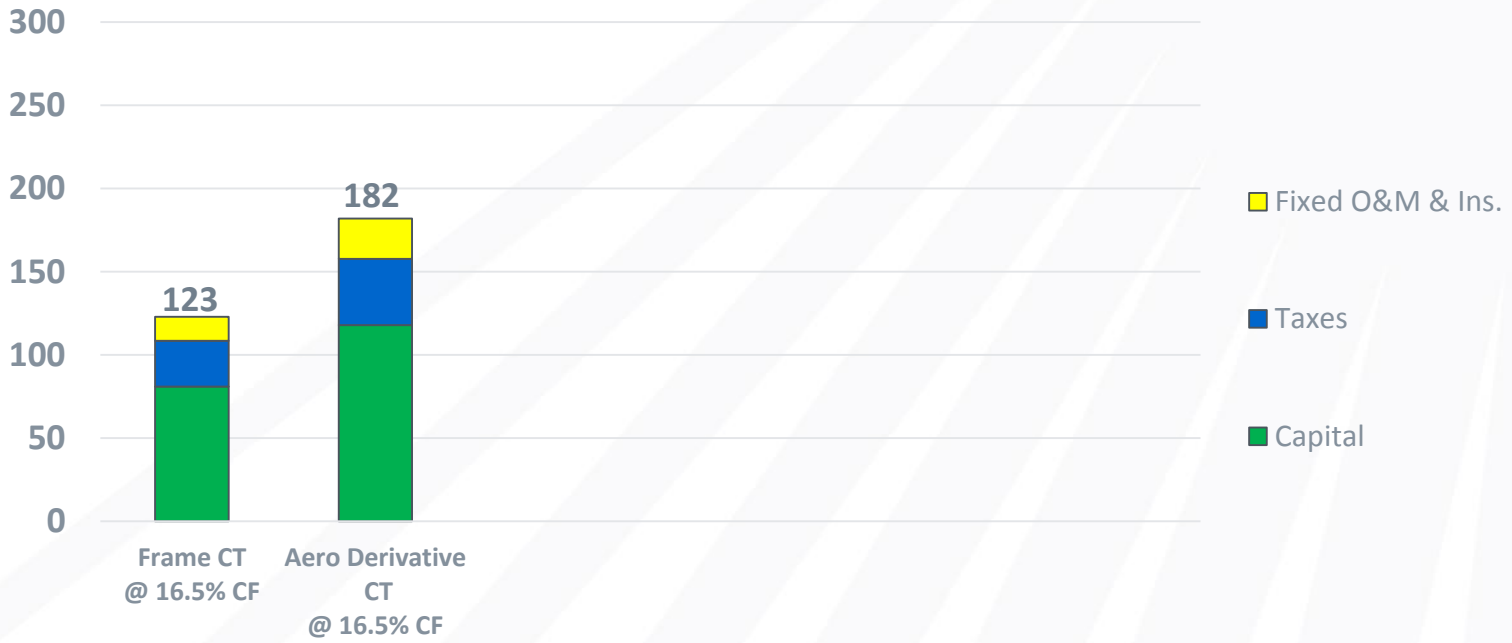
Capacity Cost [$/kW-yr]



DSP Plant vs. Combustion Turbine in Arizona

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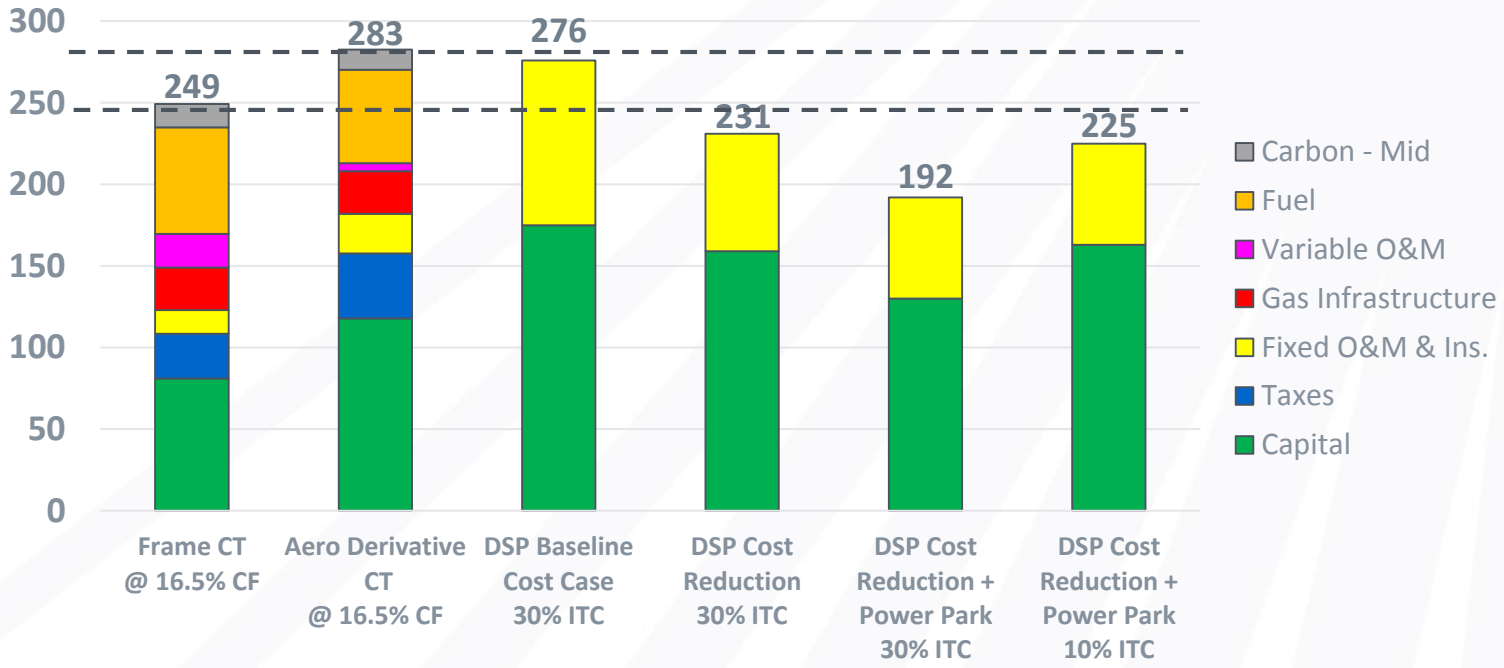
All-In Capacity Cost [$/kW-yr]



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.
- CSTP Needs:
  - Address siting issues
  - Accelerate deployment
  - Cost reduction
  - Stakeholder Outreach

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Thank you for your attention!

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