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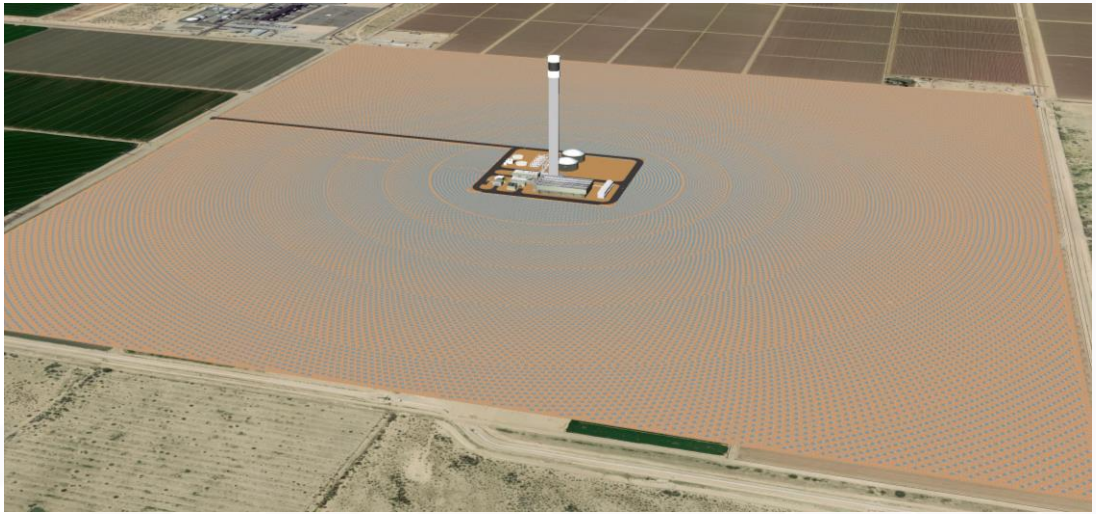


Dispatchable Solar Power

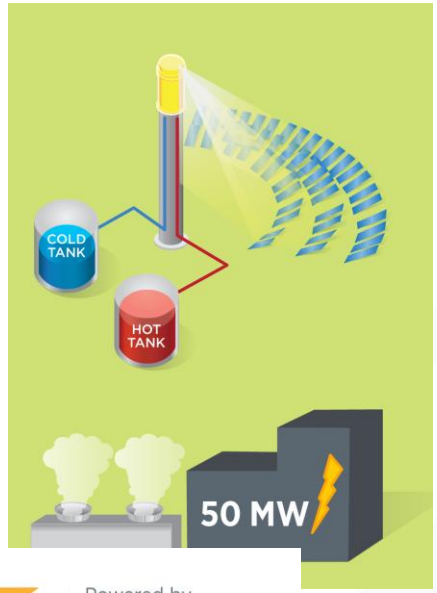
Adapting CSP to modern grid and off-taker needs

Hank Price, Managing Director
Solar Dynamics LLC

CSP: Flexible Designs for an Evolving Grid

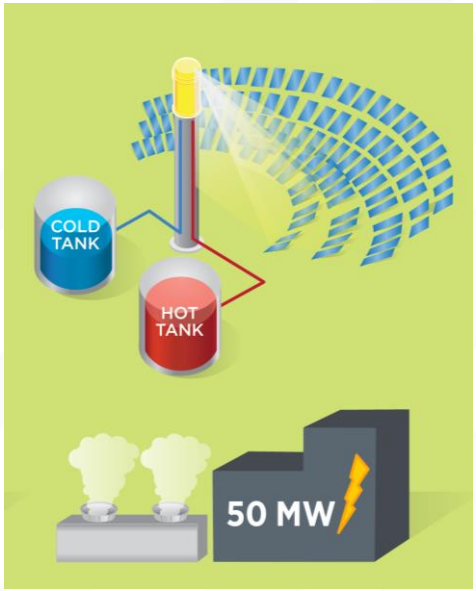
‘Peaker’

4 to 6 hours of storage
Capacity Factor <20%



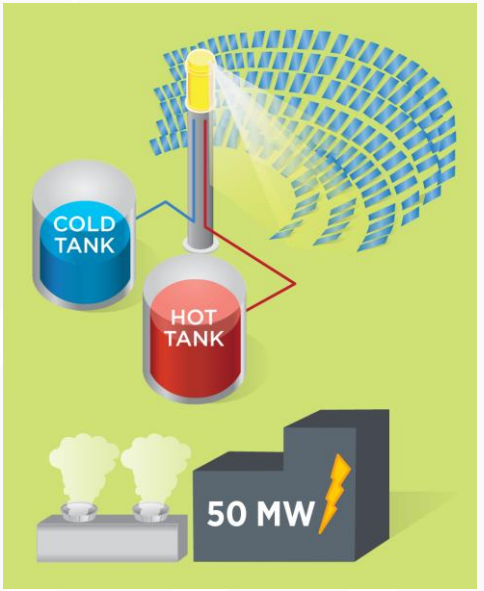
‘Intermediate’

6 to 9 hours of storage
Capacity Factor 30 to 50%



‘Baseload’

≥12 hours of storage
Capacity Factor >50%



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Hybridization of CSP

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- **Hybridization with fuel backup**
  - 5 SEGS plants demonstrated >100% 0n-peak capacity factor each for 15 years continious.
  - New studies show that 2-10% fuel backup could guarantee 100% resource availability for peak demand.
  - Fuel back up can be from green fuels.
- **Hybridization with PV**
  - PV can be collocated
  - PV can be used for internal parasitic consumption (DEWA)
  - PV can be used to augment thermal storage (Midelt concept)
- **Grid hybridization**
  - Power from the grid can be used to charge thermal storage
  - Could be a form of regulation or to consume low or negatively priced energy.

Example of CSP Peaker Concept

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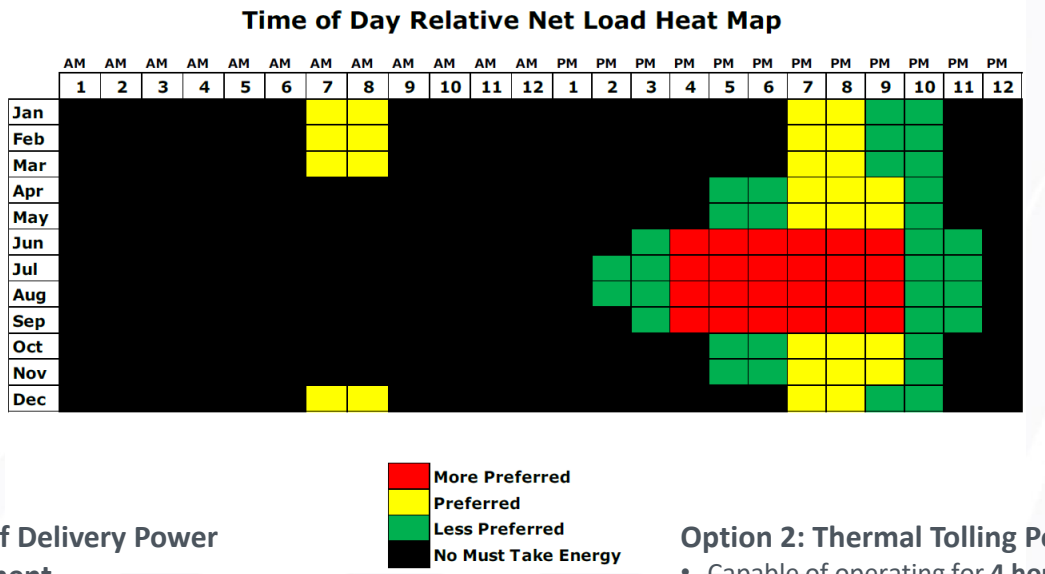
Arizona Public Service 2017 Peaking Capacity RFP



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 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

U.S. DOE SunShot: Dispatchable Solar Power Plant

Tech 2 Market

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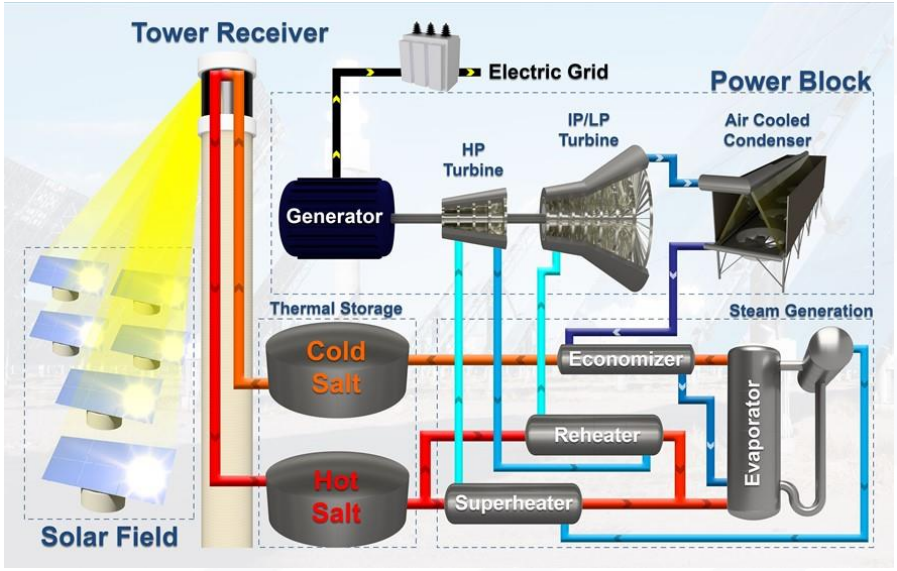
Dispatchable Solar Power (DSP) Plant

Uses Conventional Molten-Salt Tower Technology



- 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

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Sargent & Lundy

Morse Associates

BlüNebü

K&A

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Dispatchable Solar Power Plant Design

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DSP 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	115°F
Solar Receiver design duty	**400 MW_t**
Solar Multiple	**0.65**
Tower Optical Height	560 ft
Total Heliostat Area	700,000 m^2
Solar Field Area	640 acres
Storage Capacity (MWh electric)	1,150 MWh_e
Storage Capacity (hrs of turbine op.)	**5 hrs**
Annual Solar Resource	2,685 kWh/m^2
Annual Gross Capacity Factor	**16.5%**
1st year Net Generation	**334.2 GWh_e**

DSP Plant Design

- Large power plant mated to small solar field
- Produces 4 hrs/day on average
  - Compared to Solana 10 hrs/day
- 5 hours of thermal storage
  - Stores energy during the day to dispatch at night
- Design optimized to produce full power during hot AZ summer afternoons.
  - Uses hybrid cooling to minimize water use.
- Designed to fit on square mile plot of land to simplify development.

DSP Plant Output for APS TOD Schedule

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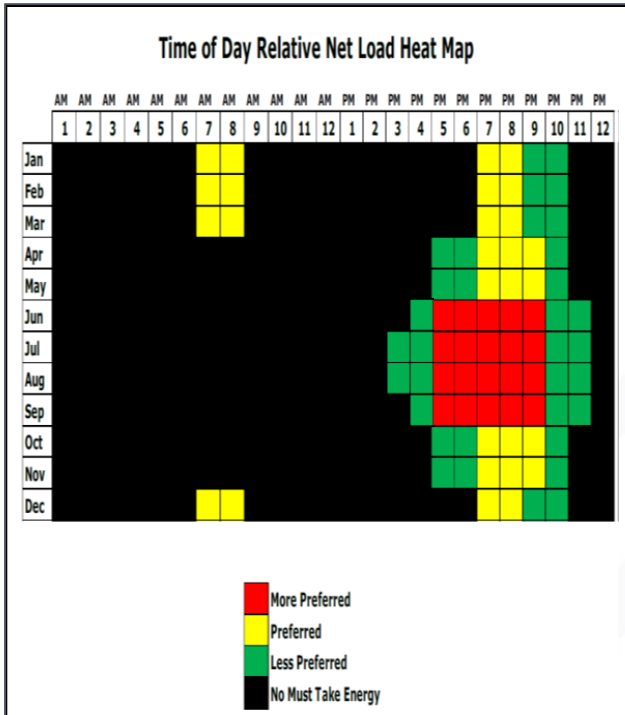
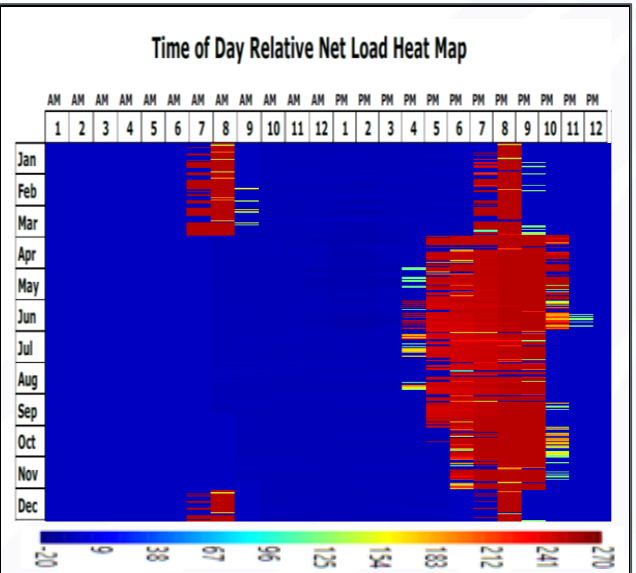


(a) APS Peaking Capacity TOD Periods



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

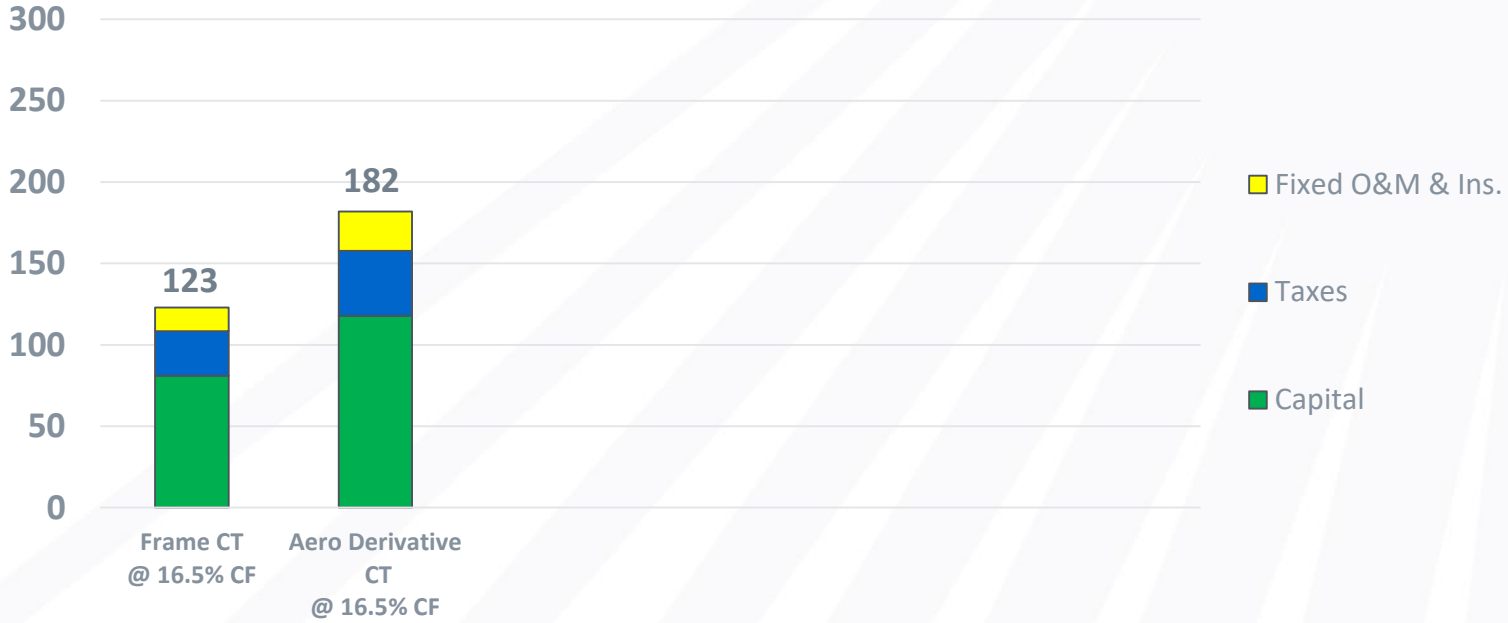
This shows the modeled output of a DSP plant optimized for a specific TOD schedule requested by Arizona Public Service (APS).

- The plant achieves high capacity factors during the more preferred and preferred TOD periods **91% & 83%.**
- Approximately **82%** of the total energy from the plant is delivered during these periods.

DSP Plant vs. Combustion Turbine in Arizona

SolarDynamics

Capacity Cost [$/kW-yr]



DSP Plant vs. Combustion Turbine in Arizona

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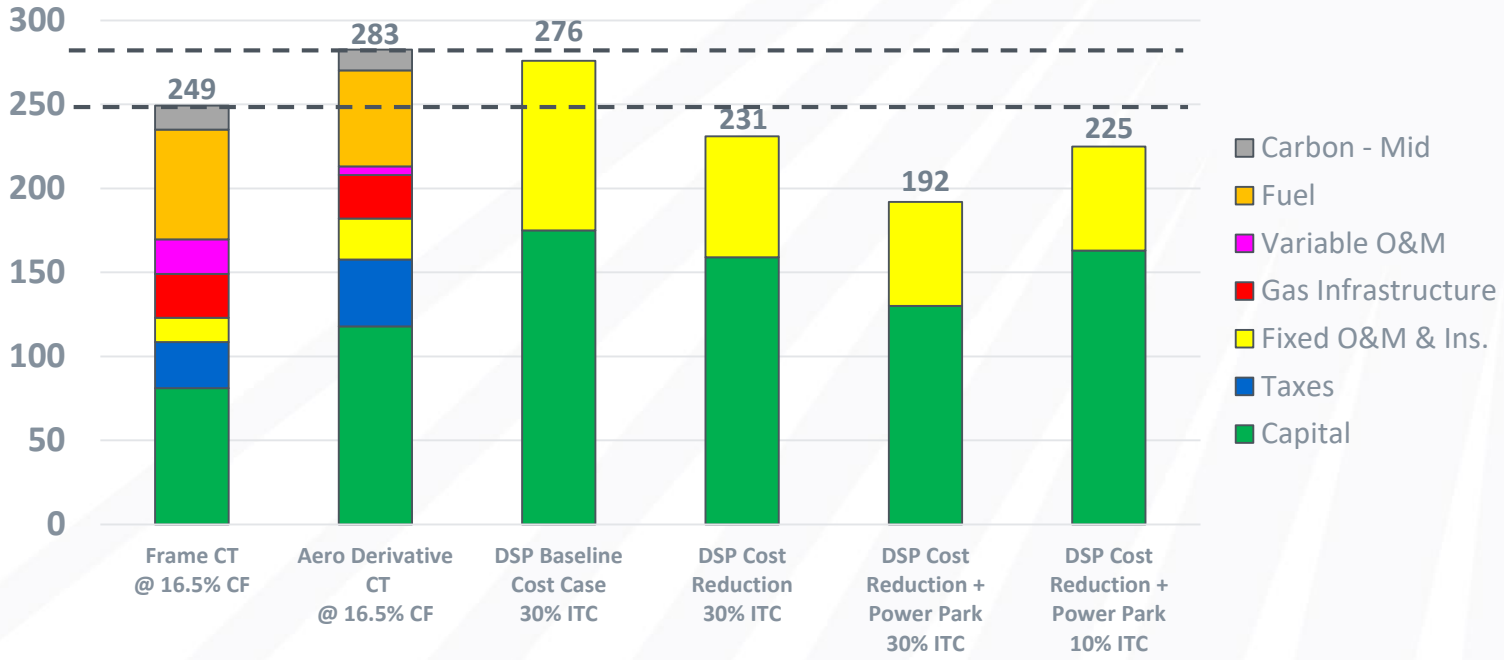
All-In Capacity Cost [$/kW-yr]



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Conceptual Design for Trough Peaker

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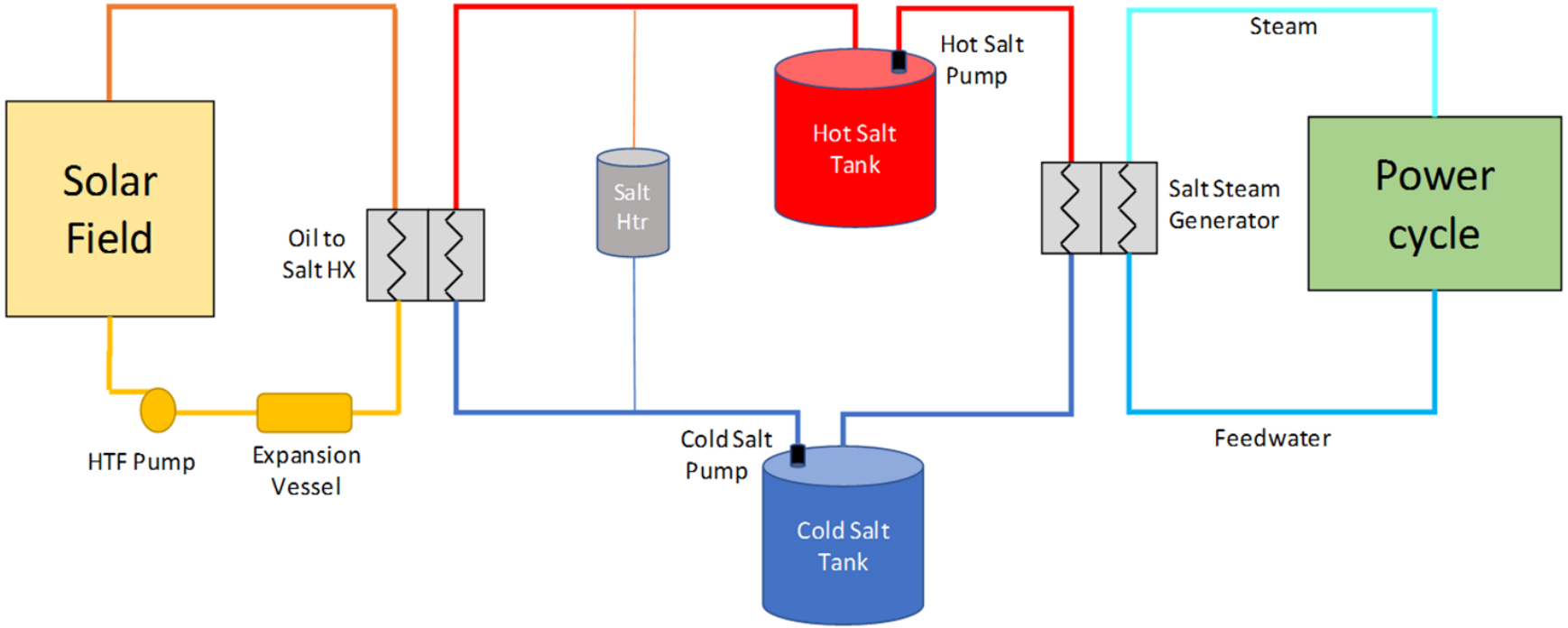

CSP Learning Curve

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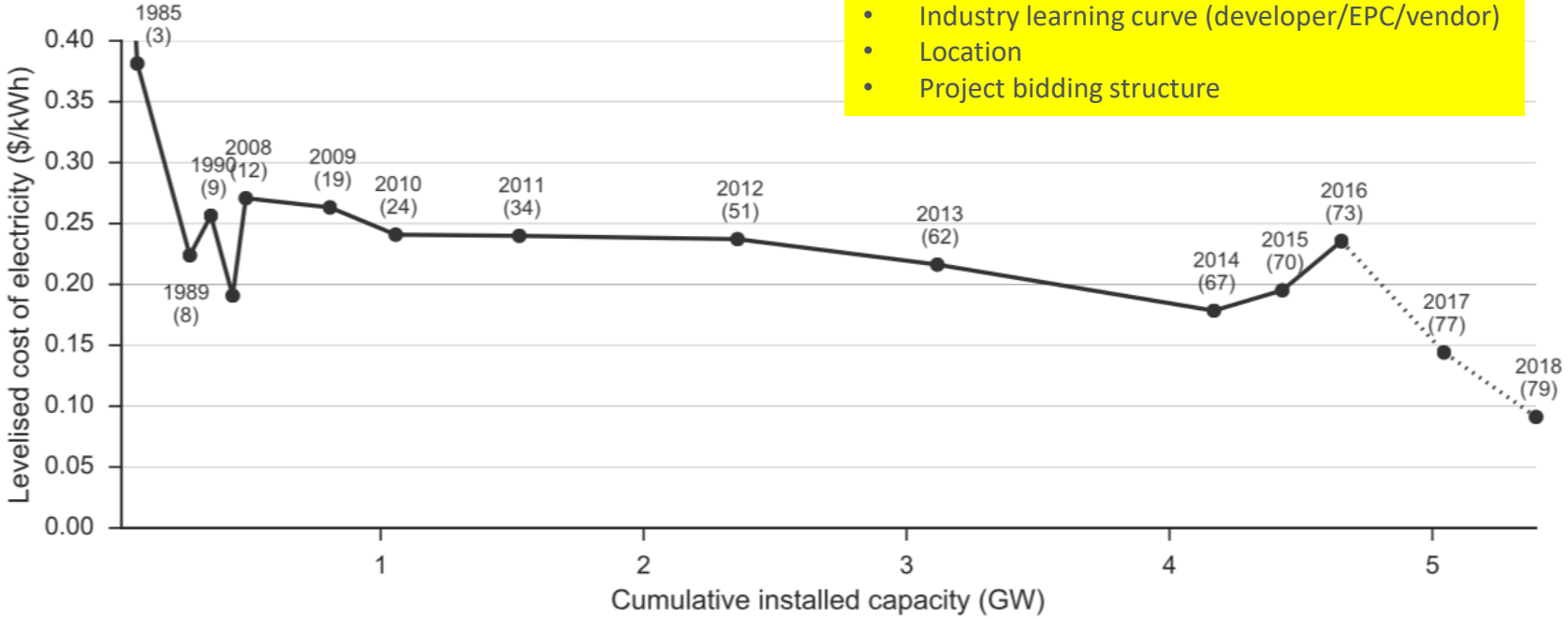
Key influences on cost:

- Solar resource
- Project size, power park, standard design
- Industry learning curve (developer/EPC/vendor)
- Location
- Project bidding structure



Source: Lillestam, Labordena, Patt and Pfenninger, Nature Energy, 2017

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Dispatchable Solar Power Plant - Final Report

https://www.osti.gov/biblio/1418902-dispatchable-solar-power-plant-project